University of Southern Queensland

Faculty of Health, Engineering and Sciences

Investigation into implement status awareness for autonomous tractors

A dissertation submitted by

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ENG4111/4112 Research Project

Towards the degree of

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Abstract

Autonomous tractors are becoming more prevalent within agriculture. However, there is one thing that is hindering these machines from taking the role of an operator. The driver is currently the perception of the tractor and the only system that can stop the machine if something is about to or does go wrong. Developing a system that allows the tractor to have a better understanding of what it is doing and how its implement is operating will mean the requirement to have an operator sitting in the tractor seat is decreased.

The aim of the project is to determine if information exchanged via a tractor's CAN Bus system can provide a sense of machine perception for autonomous applications.

The first part of the project involved designing a testing methodology that allowed a range of implements and operating conditions to be tested. From the testing methodology, a system was set up to collect messages from a range of given sensors on the tractor via the CAN Bus system. The testing was then carried out following the designed procedure while recording the operating status of the tractor to a computer. This raw data was then sent to John Deere to be converted from hexadecimal into usable Matlab file format. The data was then exported into Excel for further analysis and graphing.

From the results analysis, it can be concluded that the engine % load is the best indicator of an issue occurring with the implement. Rear hitch height, engine fuel usage and engine RPM are also parameters that showed promising results.

Overall, the sensitivity of the in-built sensors is not suitable without refinement to provide a good understanding of what the implements status is. This project has shown that CAN Bus based implement awareness systems have potential, however a large amount of refinement and work needs to be completed to ensure the system is consistent and reliable, and sufficiently responsive to allow an autonomous tractor to operate safely and efficiently.

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I declare that all work in this dissertation including concepts, designs, experimental work, results, evaluations, and conclusions are my own work expect where indicated and acknowledged.

I further declare that the work completed is original and has not been submitted previously for any form of assessment in another course or institution, except where specifically stated.

Sam Green

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A massive thank you to Tyler Schleicher and Brandon McDonald for parsing the log files and converting them into Matlab format so that they could be used on my end, without your generosity this project would not be possible. Also the constant emails and messages backwards and forwards trying to get the parameters I wanted in the data are muchly appreciated, even though most conversations would take many days due to the time zone difference.

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Abbreviated Terms

ATTA – AutoTrac Turn Automation

CAE – Centre for Agricultural Engineering (USQ)

CAN Bus – Controller Area Network Bus

ECU – Electronic Control Unit

GPS – Global Positioning System

PTO – Power Take Off

SCV – Selective Control Valve

Chapter 1 Introduction

1.1 Background

Agriculture will always be a growing industry as there will always be a requirement to feed the ever-expanding worldwide population. It is predicted that the world's population will be 10 billion by 2050, 3 billion more than in 2010. Agriculture will need to produce 56% more food by 2050, meanwhile suitable land is constantly being consumed by expanding cities and towns (Ranganathan et al. 2018). The large push towards reducing greenhouse gasses in the last couple of decades is also impacting agriculture as it contributes approximately 13% of Australia's greenhouse gas emissions (Climate Council 2021). In an attempt to improve the efficiency of farming, and make better uses of the resources available, autonomous tractors have been developed to undertake the monotonous jobs that have previously been undertaken by farmers.

Self-driving tractors have been around since the 1920's when Frank Zybach devised a tractor guide that would lead the machine along concentric circles around the field (Arens 2021). While this development occurred very early on, limited improvement occurred until the 1990's where the Silsoe Research Institute developed a driverless tractor system designed for vegetable and root crops. The modern autonomous tractor as we know it today wasn't established until the introduction of the ITEC Pro guidance system from John Deere which allows field operations such as navigation and end turns to be performed (Bear Flag Robotics 2022). The further release of Deere's AutoTrac Turn Automation in 2017 allowed the automation of end turns where-by controls such as lifting the hydraulics or 3-Point linkage can be performed by the tractor without the intervention of the driver (Spudman 2017). Autonomous tractors are heavily reliant on sensors to determine how both the machine and implement are operating. Sensors such as seed counters for each individual row have been built into planters and other implements for many years. The autonomous tractor itself has a variety of cameras and other sensors to guide it through the field and avoid obstacles when required. This technology has been crucial in the formulation of autonomous tractors as we know them today. The sensors of more advanced and modern implements communicate to the tractor via the CAN Bus, however the tractor does not have a way of determining the operating condition of simpler implements that don't have their own on-board sensor systems such as cultivators, deep rippers or PTO mulchers. Investigation needs to be undertaken to determine if any existing sensors on the tractor can be related to the operating conditions of the implement, and if they would be suitable to be used as a control method for the tractor.

The outcome predicted from this research project is to provide an understanding of what sensors are already used on modern tractors, and how they can be used to provide an autonomous tractor a better interpretation of the state of operation of the implement behind it.

1.2 Project Aim

The aim of the project is to determine if information exchanged via a tractors CAN Bus system can provide a sense of machine perception for autonomous applications.

1.3 Project Objectives

- Develop a test procedure to simulate various field operational issues to assess machine perception.
- Assess the utility and sensitivity of information exchanged on a tractor CAN Bus for machine perception purposes.
- Develop recommendations for CAN Bus based perception systems that inform autonomous operations.

Chapter 2 Literature Review

2.1 Summary

The purpose of the literature review is to investigate, analyse and evaluate autonomous tractors and their sensor systems. The development of autonomous tractors continues to grow, and modern implements are evolving to communicate their state of operation with the tractor to allow the autonomous smarts to make decisions based on the outputs of the sensors. However, there is currently no way for these smart tractors to understand how a simple implement is operating as this is usually undertaken by the driver. While many implements in the future will have their own computer systems, there are many machines that will not, and therefore a tractor-based sensor system would be ideal as it would work with all types of implements.

2.2 Autonomous tractors and the need for perception

It is critical that an autonomous tractor can operate in the in the field without human interaction, however, still be able to take commands from the remote operator. As a result of previous work in this field, Blackmore et al. (2004) recommended the following features should be demonstrated by an autonomous tractor in the field:

- Remain in a safe and controlled operation state, especially in the case of a partial system failure
- Ability to operate with and around other machines in a co-ordinated manor
- Send and receive information wirelessly in regard to tasks to complete and operating status
- Be able to undertake a large variety of farming operations

To complete these tasks safely, autonomous tractors use on board sensors to detect obstacles including people, animals and other vehicles that may enter into the safe operation zone of the machine (Stentz et al. 2002). It is also critical that the tractor can interact and have an awareness of unstructured environments such as natural terrain allowing it to gain navigational control and optimise machinery operations (Baillie et al. 2017).

While an autonomous vehicle must understand its immediate surroundings, it is also important that it can monitor and understand what the implement is doing. Through environment, vehicle and implement monitoring, the state of operation can be determined. Using the information from on board sensors, the tractor can adjust its operating parameters to best perform the job at hand (Jensen 2022). Noah Schwartz, a head perception engineer at Bear Flag Robotics "says there are a lot of robust AI (artificial intelligence), models and algorithms built into the system to ensure the tractor has a constant feed of high-quality information about what is going on in its environment" (Jensen 2022).

Perception in autonomous tractors is an essential requirement to allow the machine to detect issues before they become a safety hazard and endanger the lives of nearby people or cause damage to property. Driverless equipment in agriculture has a major disadvantage when compared to automated robots in factories, the machines have to operate around the general public. Given the autonomous tractors are operating in the public's eye, they must be seen to be doing the correct thing at all times. It would only take a single "news report of a malfunctioning machine crashing into a neighbour's yard or a machine that fails to recognise a dog or child and runs [them] over to spark a firestorm of negative publicity" (Lowenberg-DeBoer 2002). When an issue arises and harm is caused to either the operator, the public or someone's property, there is a legal requirement to compensate the victim. There is major concern as to who will take the blame if an autonomous tractor were to cause harm. In terms of autonomous robots, faults can be considered a machines fault and therefore the machine is responsible or the programmer or manufacturer who designed the system. Currently it is accepted that the autonomous machines are not smart enough to be able to cause an issue if they are designed and programmed correctly. Current legal frameworks show that the manufacturer or programmer of the machine will most likely be held responsible in the case of an accident (Petrovic 2021).

Research work completed by Torrance (2020) investigated autonomous tractors and developed a comparative test procedure for the assessment of performance of autonomous tractors. Prior to the Torrance (2020) investigation, the only standardised comparative testing criteria that assesses the mechanical capabilities for tractors was the Nebraska Tractor Test (Nebraska Tractor Test Laboratory 2022). The aim of the Nebraska Tractor Test is to compare the functions and capabilities of different makes and models of tractors so they can be compared to allow the farmer to choose the most appropriate tractor for their operations (Torrance 2020). The Nebraska Tractor Test only assesses the mechanical performance of the tractors and does not consider the usability or control capabilities. There has been work by Desai (2012) which adds usability requirements to the typical tractor test by including row width adaptation and manoeuvrability tests for the row crop tractors; these tests however are currently not universally accepted. Torrance's work further developed the tractor testing procedures by adding tests more suited to autonomous tractors and how capable current tractors are at being autonomous (Torrance 2020).

2.3 The CAN Bus system on modern agricultural machinery

Most modern tractors utilise a controller area network (CAN) Bus system for controller and sensor communication within the machine and certain implements. The CAN Bus is a two-wire communication system whereby all information has a given CAN address. This system allows sensors to broadcast information to the rest of the system where it can be accepted by its respective controller (CSS Electronics 2022). A diagram showing the typical setup of a CAN Bus communication system can be seen in Figure 1. (Maurizfa et al. 2020)

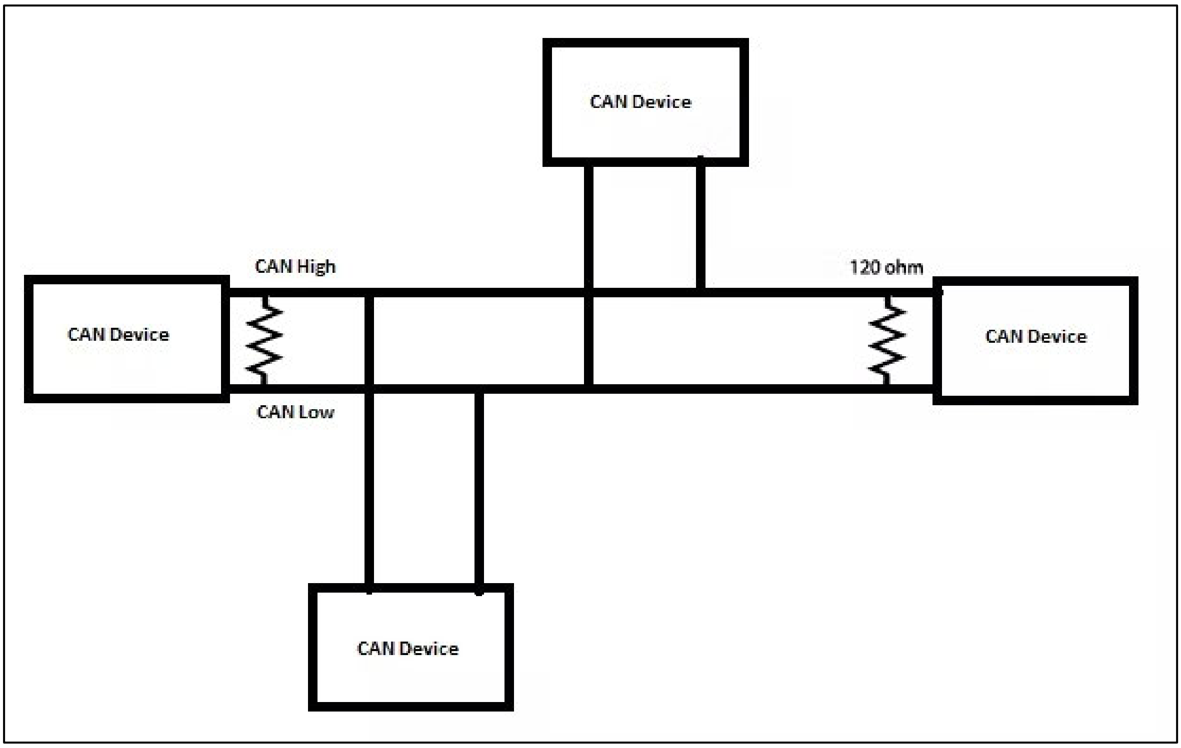

Figure 1 - Basic CAN Bus wiring diagram (Maurizfa et al. 2020)

CAN Bus systems allow an increase in machine productivity, more rapid problem diagnosis and a method for implements to communicate with the tractor. The CAN system is standardised across many industries using the Society of Automotive Engineers standard SAE J1939 (Copperhill Technologies 2022). This standard allows the diagnostics and control of machine operating parameters including engine control, transmission control, brake control (Marx 2015). As a subdivision of SAE J1939, the International Organisation for Standardisation (ISO) created ISO 11783 which is defined to be the universal standard for CAN communication and serial control for agricultural and forestry machinery (John Deere 2013). One of the major sections of ISO 11783 is the ability for the on-board computer to communicate with the implement. This allows sensors on the implement to be seen by the tractor as well as the tractor being able to pass control information back to the implement such as a sprayer or planter (Tohnny Van Do 2021).

Electronic control units built into the machine communicate the information necessary for effective management from the internal sensors via the CAN Bus. Sensors are located throughout the machine, especially the engine, gearbox and cabin, allowing the machine to understand its operation state (Čupera & Sedlák 2011). The CAN Bus allows sensors to communicate with the machine, however, it also allows controllers to send information and commands to actuators and control elements that can change the operating state of the machine to improve efficiency and productivity.

The CAN Bus also allows quicker diagnosis of issues in the electrical system. Communication with John Deere machines occurs via the Service ADVISOR™ computer program. Using an Electronic Data Link (EDL) and the Service ADVISOR™ program, the technician can observe and trace communications between controllers on the machine to track down issues (John Deere 2013).

2.4 Sensors and technology that are on the tractors currently

Modern machinery consists of technology and sensors that allow the operator and the machine to have a greater understanding of its operating status. The control elements of the tractor communicate with the various sensors via the CAN Bus system and the Electronic Control Unit (ECU). Figure 2 shows the communication between the ECU and the other nodes of the CAN Bus system.

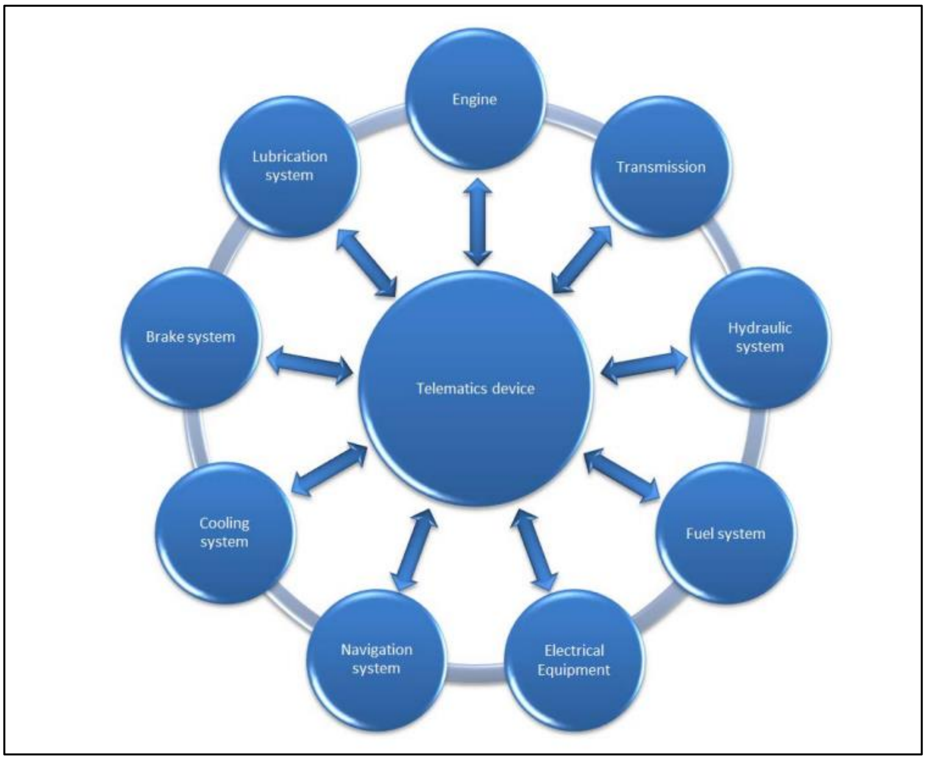

Figure 2 - Diagram of tractor systems interaction with a telematics device (Didmanidze et al. 2021)

The tractors control and sensor system can be broken into 5 major groups, (Didmanidze et al. 2021)

- Transmission
- Engine
- Hydraulics
- Drivetrain
- Navigation

Within these groups there are individual controllers that talk to each other and the respective sensors for that sub-section. Below is a list of sensor values that have been found on the CAN of a John Deere 6120R that may be useful to determine the general operational characteristics of the tractor and implement.

- Time
- Latitude
- Longitude
- Altitude
- Course
- Pitch
- Roll
- Speed
- Wheel Based Vehicle Speed
- Engine Coolant Temperature
- Engine Crankcase Pressure
- Engine Fuel Rate
- Engine Fuel Temperature
- Engine Intercooler Temperature

- Engine Oil Temperature
- Engine Speed
- Req Engine Speed
- IVT Set Speed
- Rear Hitch Height
- Transmission Oil Temperature
- Engine Load
- Rear PTO Speed

The research undertaken by Torrance (2020) determined that the John Deere 6120R was a reasonably well suited to autonomous operations due to advanced headland management and operational safety protocols, however the tractor is limited from driverless capabilities due to a lack of depth perception and awareness of its surroundings.

While not directly related to the agriculture industry, autonomous vehicle standards and information can be drawn from the automotive industry. SAE J3016 provides a framework that defines a vehicles level of automation. A cars automation can be classified into 6 levels ranging from level zero where a vehicle will provide warnings and temporary assistance through to level five where complete driverless capabilities are available in all driving conditions (Shuttleworth 2019). The intermediate levels and their characteristics can be seen below in Figure 3.

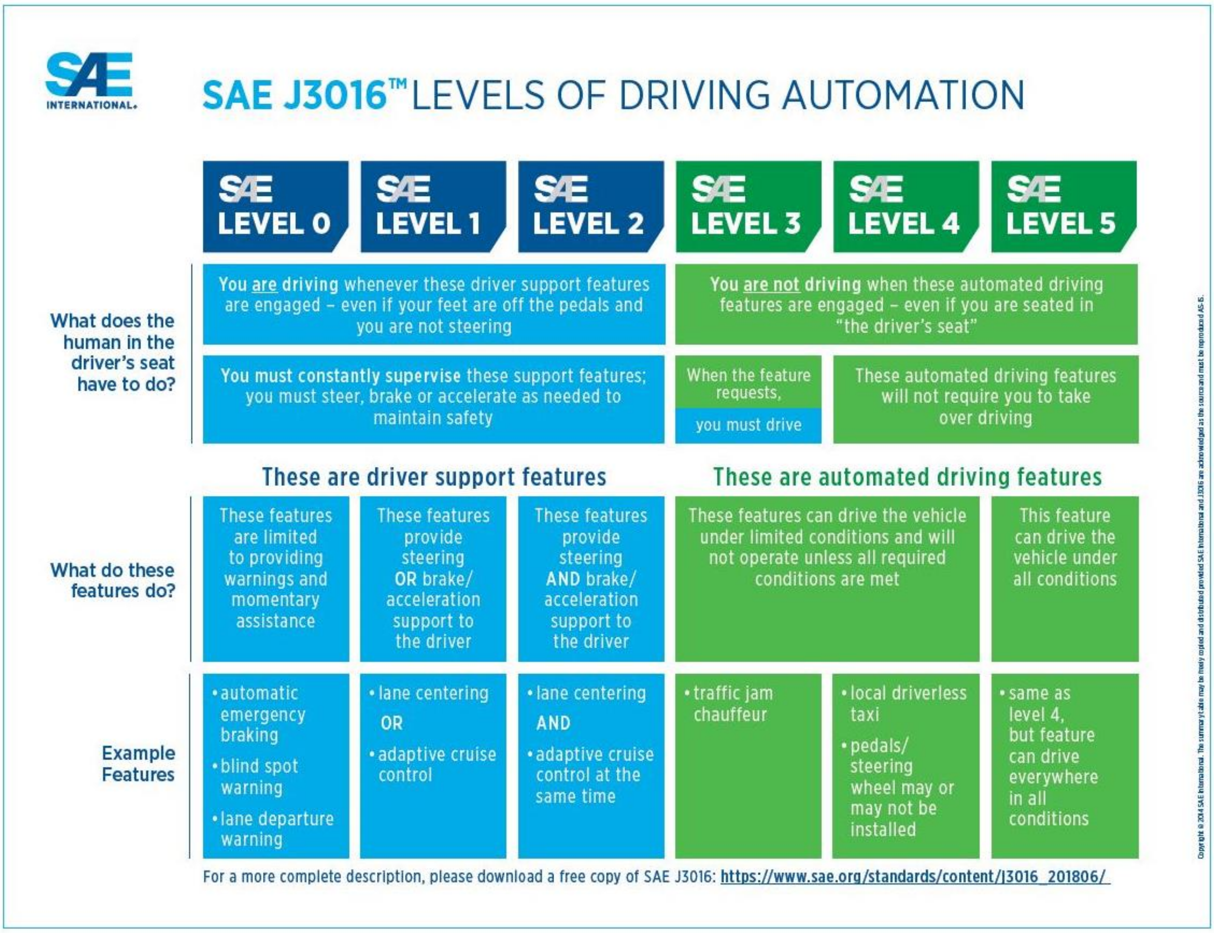

Figure 3 - Graphical representation of SAE J3016 (Shuttleworth 2019)

A similar description has been developed by Case IH Agriculture where there are 5 levels of automation for agriculture; guidance, coordination and optimisation, operator assisted autonomy, supervised autonomy and finally full autonomy(Case IH 2022). Figure 4 shows Case IH's adaptation of the automation levels.

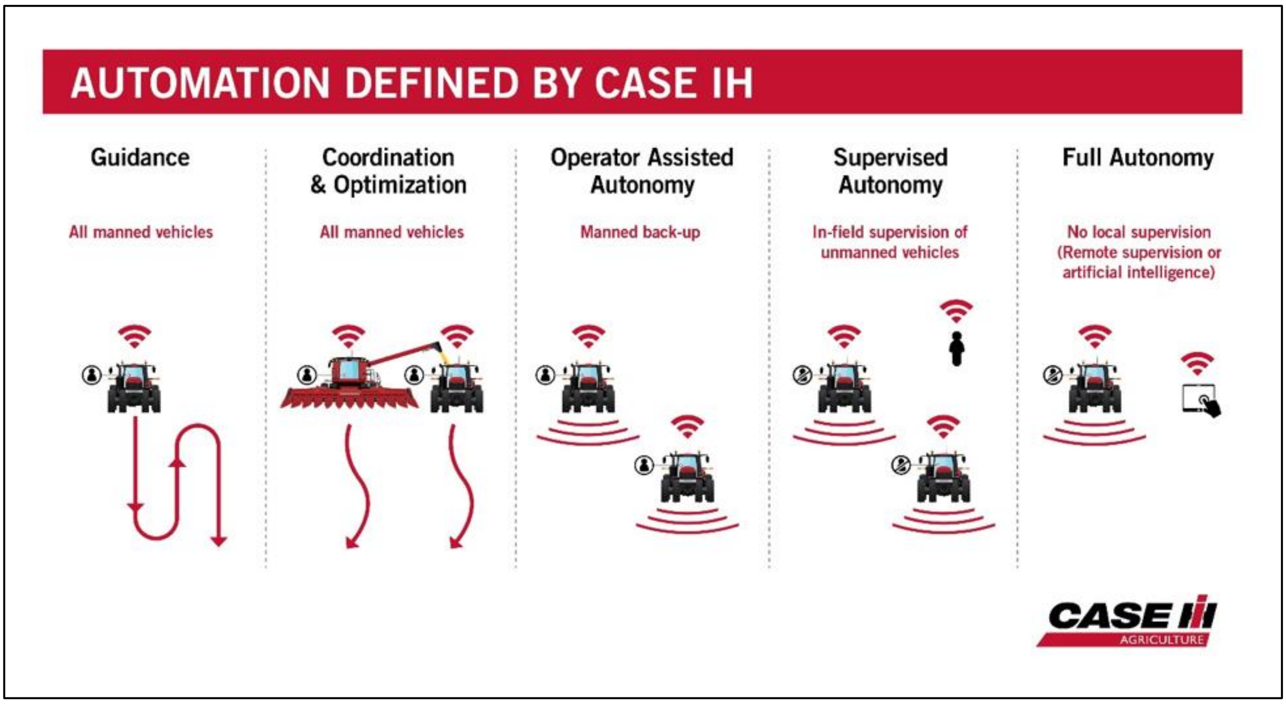

Figure 4 - Levels of automation described by Case IH (Case IH 2022)

Guidance is based around GPS technology and allows the tractor to operate along a prescribed track. Coordination and optimisation is a level that allows communication between vehicles in the field, as well as path planning. Operator assisted autonomy involves automatic and manual adjustments of the implement and tractor while an operator remains in the vehicle for supervision. Supervised autonomy is the control of multiple machines from only one operator, the operator controls one machine while the others talk to the leading machine to receive operating parameters and desired conditions. Full autonomy allows the machines in the field to be operated from a remote point without the requirement for human intervention, however, this requires the capacity for perception and implement awareness (Case IH 2022).

For John Deere to consider a tractor to be autonomous, it must comply with level four or above. Currently, the 6120R can be considered a level three due to its advanced AutoTrac Turn Automation (ATTA) which allows the tractor to steer, change the throttle and control the implement before completing a headland turn, however it still requires human intervention to activate the turn sequence (Torrance 2020). For the tractor to develop to a level four, it requires a system that will allow it to operate without any human intervention.

2.5 Testing equipment and procedures

Prior to using any of the equipment, it is critical to determine suitable operating speeds and depths. Through investigation it was found that 3kph is the most suitable speed for PTO mulching as seen in Figure 5. The operation depth was set to be 150mm as this is what the machine was set to from the previous use.

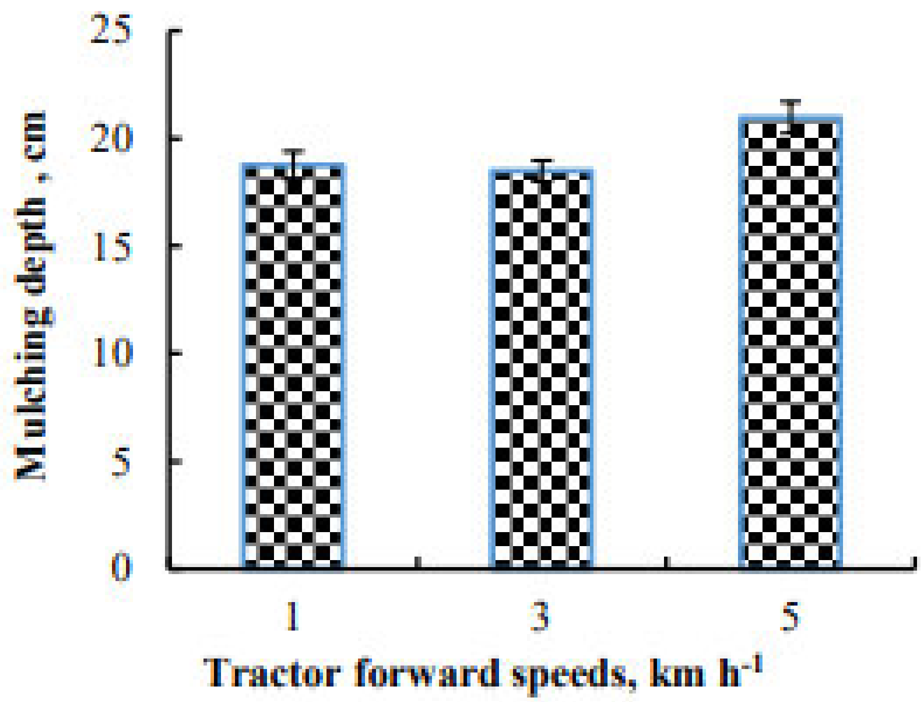

Figure 5 - Operating speeds of a PTO Mulcher (Jahun et al. 2021)

2.6 Real world issues for the tractor in an autonomous state

Tractors are currently heavily dependent on the operator in a perception sense. The operator is essential to stop the tractor in the case that an issue may occur with the machine or implement. Using sight and sound and relating back to previous experience, an operator can usually sense an issue when it occurs.

Based on the chosen operating states of an autonomous tractor being transport and 3-point linkage deep ripping, the following list of common operating issues has been developed. The issues listed below are concluded based upon previous experience operating the given machinery in the field.

Transporting

- Travelling too fast over rough terrain causing unnecessary shakes, vibrations and loads on the tractor and implement

3-point linkage deep ripper

- Ripper shank breaks off or shear pin breaks as a result of overload from hitting rocks or other obstacles in the ground
- Ripper begins to dig in too far causing the tractor to lose traction or stall as a result of incorrect operating height
- Bridging occurs across a number of tines of the ripper which results in a block up commonly caused by stringy plant material or debris laying on the surface of the soil
- Ripper is not engaged with the ground far enough causing improper soil disturbance due to incorrect operating depth
- The 3-point linkage is not lifted prior to the headland and beginning the turnaround sequence as a result of machine process error which may cause high loads on the tractor and ripper
- Rapidly changing ground incline causing the ripper to dig in further or not enough due to the tractor not changing 3-point linkage height to keep constant ground engagement depth

Using these known failure modes, an experimental procedure can be designed to replicate them in a controlled and repeatable manor so that data can be collected that will provide an insight into the sensitivity of the on-board sensors and their suitability to monitor what the implement is doing.

2.7 Knowledge Gap and Study Justification

Through an investigation of existing literature in the autonomous tractor field, it was found that there is currently no system that can detect the implements operation status using the sensors that are already built into the tractor. Therefore, the focus of this research project is to build on information gathered from both automotive industries and other agricultural work, to determine if existing sensors can provide a sense of machine and implement perception for autonomous applications.

Based on information gathered during the literature review, it is considered that the proposed project will be attainable and useable in the future. Findings gathered from this project will inform the agricultural industry as a whole, but more specifically the autonomous tractor industry. It will provide a development in autonomous technology and potentially provide the required steps to create a fully autonomous tractor based on existing tractor technology.

Chapter 3 Methodology

This chapter will consist of the formulation, development and analysis of a data collection and testing procedure to determine if an implement can be monitored through the existing CAN Bus data of the tractor. The testing procedure from which data will be collected from has been developed based upon information found during the literature review stages of the report. The testing procedure developed in this chapter will allow the implementation of experimental testing in the following chapter. This research also allows the developed testing procedure to be evaluated to determine its suitability for real world circumstances.

3.1 Research Focus

This research project draws on information and current standards from the agricultural industries while also implementing ideas and technologies from the transport and mining industries. The research aim and scope of the investigation can be seen in the following section.

3.1.1 Research Aim

The aim of this research is to determine if sensory information that is already on a tractor's CAN Bus system can provide a sense of machine and implement perception for autonomous applications. Analysis of the collected data from the designed testing procedure will allow conclusions to be drawn about the ability of the tractors sensors to determine the state of operation of the implement.

3.1.2 Research Scope

Due to the comprehensive nature of autonomous vehicles, and in particular, autonomous tractors within agriculture, the scope of this research project was narrowed down to allow for thorough testing and analysis of a given problem. The project has been limited to John Deere tractors due to the resources such as the machine and data collection technology available at the time, as well as only a small variety of testing implements. This research project is a preliminary investigation into what sensors are available on current John Deere tractors, and whether they can detect issues and changes which may reflect the implements' operating status. Further development to this research may be carried out in the future with the aim of introducing it into autonomous tractors.

3.2 Project Methodology

Based on the scope of the research, the methodology of the project can be broken down into the following processes.

1. Conduct investigation into the process of data collection from the CAN Bus system of autonomous John Deere tractors.
2. Investigate which data may be useful in determining whether an issue may have occurred with the implement.
3. Secure machinery and site to allow testing to be undertaken safely and when required.
4. Develop an experimental procedure to simulate issues occurring on basic tractor implements that do not have their own sensor systems.
5. Conduct preliminary testing to verify that the data can be collected, and the testing procedure will be suitable, then if necessary, modify the testing procedure to ensure the correct data is collected.
6. Perform experiment procedure to capture data.
7. Process and evaluate the data collected in the experiments.
8. Present the findings of the experimental procedure and develop recommendations towards CAN Bus based perception systems in autonomous tractors.

3.3 Task Analysis

The following section of the report will provide a detailed understanding of how to set up the tractor, the implements being used and the data collection equipment. The first part of the method involves defining the preliminary methodology testing, this is then followed by the main body of the methodology and finally the data evaluation.

3.3.1 Preliminary methodology testing

Preliminary testing will be undertaken to ensure that the machines can be used and modified as required for the testing procedure to deliver the desired results. Performing this testing will allow any modifications to be undertaken regarding the methodology. Setting the machine up and using the implements will provide an understanding of how the data collection will operate.

Preliminary methodology to validate testing procedure

- Connect to CAN Bus system and log data performing simple operation such as driving through the field.
- Analyse data recorded to ensure suitable data has been collected and it is in a form that can be further analysed or displayed.

3.3.2 Testing Procedure

The modes of failure that have been identified are based on personal experience and general farming operations. Table 1 seen below shows the development of the possible modes of failure that may be encountered in the field for a 3-point linkage ripper and a PTO powered rotary hoe and in a general transport operating mode. The table also describes the general process of how the issue can be replicated in a controlled manor.

Table 1 – Issues encountered in the field and how they can be simulated in a controlled and repeatable manor

Implement	Modes of failure	How the issue can be simulated
3-Point linkage deep ripper	Base run	Run the tractor and ripper in the field to give a baseline data form to reference the rest of the ripper data from.
	Ripper shank shear pin breaks	Once completing the first pass, fit a smaller shear pin or bolt to the shank of the ripper that will result in the tine 'breaking off' when it reaches a buried piece of timber within the field.
	Ripper is digging in too far	With the ripper at a suitable operating height, complete a pass in the field. Then force the ripper to operate at a deeper depth to simulate an increased load on the machine.
	Bridging has occurred across 2 or more tines	Once the baseline run has been recorded, a timber board can be partially buried in the soil that is collected by 3 of the tines. This board then will create a bulldozing effect and collect the soil simulating a blockage.
	Ripper is not engaging in the ground enough	After the initial run, lift the ripper out of the ground so that less ground engagement is achieved and then repeat the testing procedure.
	Tractor fails to lift implement out of the ground prior to executing headland turn	Travel along with the implement in the ground, then reach the end of the run where the wheel tracks are most prominent in the headlands and lift up after the headland. This will mean that the ripper is operated through the more compacted areas of the field where it would typically be lifted up for the turn around procedure.
	Failure to react by lifting or lowering the 3PL when going through a washout	Operate the machine with the deep ripper through a washout without changing the 3PL height to apply loads to the tractor that it may not see in regular operation.

PTO powered rotary hoe	Base run	Operate the tractor and rotary hoe in the field under normal operating conditions to provide a reference for the rest of the PTO based data both in the field and on the dynamometer.
	Operating in already ripped ground	Operate the rotary hoe over a section of the field that has already been ripped with the deep ripper to provide different operating conditions to test the data collection methods.
No implement	Base run	Run the tractor in the field to get a base run of what to expect from the data and the machine.
	Hitting large ruts at speed in a transporting situation	Operating the tractor and driving through a pothole or washout and measuring the pitch, roll and other acceleration values from the GPS receiver.

The lists provided below are a more detailed description of the modes of failure and what operating parameters such as speed and cutting depth will be used.

No Implement

- Base run
    - Speed – 3kph, 5kph, 10kph
    - Travelling in a straight line using autosteer guidance
    - Operate in the field that the ripper testing will be carried out in
- Transporting
    - Speed – 3kph, 5kph, 10kph
    - Travel in a straight line using the autosteer guidance
    - Roughness of the ground (driving on rough cultivated ground)

3-Point linkage deep ripper

- Base run
    - Speed – 3kph, 5kph

- Travel in a straight line using the autosteer guidance
- Ripper depth of 200mm, 300mm, 350mm
- Operate the machine with the implement in the ground from one end of the field to the other then turn around and come back

- Ripper shank hear pin breaks
  - Speed – 3kph, 5kph
  - Travel in a straight line using the autosteer guidance
  - Ripper depth of 200mm, 300mm, 350mm
  - Fit pre-cut shear pin to the ripper
  - Bury a piece of timber in the soil half way along the run which will cause the shear pin to break and replicate a broken ripper shank
  - Operate the ripper at 300mm depth from one end of the field to the other with the timber in the middle of the run

Figure 6 - M24 Bolts used as shear pins for the ripper shank breakage testing

Figure 7 - Shear bolt installed in deep ripper ready for testing

- Ripper is digging in too far
  - Speed – 3kph, 5kph
  - Travel in a straight line using the autosteer guidance
  - Initial depth of 300mm then lower to 500mm half way through the run
  - Operate the machine at 300mm for half the run and then lower to 500mm while attempting to maintain the same ground speed, at the other end of the field, turn around and repeat the same process. Then repeat the process with a starting depth of 100mm.
- Bridging occurred across two or more tines
  - Speed – 3kph, 5kph
  - Travel in a straight line using the autosteer guidance
  - Ripper depth of 200mm, 300mm and 350mm
  - Boards of timber were screwed to the top of 2 tines as seen in Figure 8 to capture a large piece that is laying on the ground.
  - The large piece of timber is partially buried in the soil half way along the run, it will be picked up by the ripper shanks and then get caught under the screwed-on pieces causing the block up.

Figure 8 - Boards attached to the ripper shank to catch the large piece laying on the ground

Figure 9 - Board of timber bridging 3 ripper tines causing a block up of soil

- Ripper is not engaging in the ground deep enough
    - Speed – 3kph, 5kph
    - Travel in a straight line using the autosteer guidance
    - Initial depth of 300mm then raise to 100mm half way through the run
    - Operate the machine at 300mm for half the run and then raise to 100mm while attempting to maintain the same ground speed, at the other end of the field, turn around and repeat the same process. Then repeat with a starting depth of 500mm.
- Tractor fails to lift implement out of the ground prior to headland turn
    - Speed – 3kph, 5kph
    - Travel in a straight line using the autosteer guidance
    - Ripper depth of 200mm, 300mm, 350mm
    - Operate the machine in standard configuration, however, continue with the implement in the ground into the headland area of the field to demonstrate a section that shouldn't be ripped in general field operation
- Failure to react to 3PL height when going through a washout
    - Speed – 3kph, 5kph
    - Travel in a straight line using the autosteer guidance
    - Ripper depth of 200mm, 300mm, 350mm
    - Operate the machine through a washout and keep the 3PL at the same height, this will result in less and greater levels of ripping depending on the angle of the implement relative to the ground

Figure 10 - Bank used to simulate the washout

PTO powered rotary hoe

- Base run
  - Speed – 3 kph
  - Travel in a straight line using the autosteer guidance
  - Rotary hoe depth of 150mm
  - Operate the machine in virgin ground that has not been ripped at the desired depth and speed to get a base line set of data
- Operating in pre-ripped ground
  - Speed – 3 kph
  - Travel in a straight line using the autosteer guidance
  - Rotary hoe depth of 150mm
  - Operate the machine in part of the field that has already been ripped to give an idea as to how the machine will operate in different working conditions

The testing matrix that was used in the field to ensure all required data was collected can be seen in Appendix A. The grey boxes indicate data that was not required or able to be collected, and the green boxes indicate the data that was collected.

3.3.3 Data Analysis

After recording the log files from the CAN Bus, the files were sent to Tyler Schleicher and Brandon McDonald from John Deere in the United States of America. There, the data was parsed which converts the CAN data format (hexadecimal) into Matlab format that can be easily interpreted. For ease of analysis, the required data variables were exported out of Matlab into Excel.

Once in Excel, graphs were made for the chosen parameters to allow them to be investigated. Various other comparative values are found in excel such as averages and variance, these values can be used to compare how the machine is operating before and after the issue has occurred.

From the Excel graphs, conclusions can then be drawn as to which parameters are the best indicator of when an issue has occurred. From the chosen parameters, the best 3 will be chosen that best depict or show when a mode of failure has occurred.

Data analysis method

- Analyse data to determine if there is a correlation between the data sources collected and the issue that was created on the machine.

3.4 Resource Analysis

The resources required to allow the completion of this research project can be seen below in Table 3.1. The financial costs of each item have also been included in the table to give an idea of the overall costs of the research. The main resources required for the project include the land for testing, the tractor to perform the data collection on, and the implements to use behind the tractor. These resources are already owned by UniSQ and have been provided to allow the research to be undertaken. The data collection equipment and software will be sourced from John Deere.

Table 3.1 – Resource Requirements

Resource	Source	Cost
Testing land	USQ	Owned
Tractor (John Deere 6120R)	USQ	Owned
Deep ripper	USQ	Owned
PTO mulcher	USQ	Owned
Timber Planks	USQ	Owned
CAN Case (CAN interpretation tool)	John Deere	Owned
Laptop with CAN Bus recording software (CAN Sniff)	Student	Owned
Data storage device	Student	Owned
General tools	Student	Owned
High-visibility vest	Student	Owned
Diesel (50 Litres)	Student	$120
Shear bolts for the ripper	Student	$50

The main cost for this project is the fuel to run the tractor as the majority of the equipment and supplies will be provided by the USQ, John Deere or the student. Fuel costs are high currently, however in the sense of a whole project it is very affordable. An exact cost value for the fuel cannot be provided, however an estimation is formed for the sake of the resource requirements and planning process.

3.4.1 John Deere 6120R Tractor

The John Deere 6120R is a 2020-year model tractor that UniSQ uses to carry out general agricultural operations and to undertake testing and experimental works. The tractor has an IVT transmission that is controlled by the CAN Bus system and allows the operator to vary the travel speed infinitely. Another benefit of the IVT transmission is the ability of the tractor to reduce the gearing and increase engine revolutions automatically as the implement demands more power. The tractor is fitted with AutoTrac guidance thanks to a Starfire 6000 GPS receiver and in-built steering control valve. As the tractor is of recent build, many of the controls such as the SCV's (hydraulic remotes), PTO, 3-point linkage and other touch buttons within the cab are transmitted via the CAN Bus. All of the sensors within the tractor are also communicated with via the vehicle CAN Bus allowing the readings from the sensors to be found in one place. Images of the tractor and the Starfire 6000 receiver can be seen below in Figure 11 and Figure 12.

Figure 11 - John Deere Starfire 6000 GPS receiver that is fitted to the 6120R

Figure 12 - John Deere 6120R tractor provided by UniSQ

3.4.2 Deep Ripper

The first implement chosen for the data collection section of the research project is a Gyral deep ripper. This implement is owned by UniSQ and will be an ideal attachment for the tractor as issues can easily be simulated such as removing a tine or blocking up the area between two tines to increase drag. The deep ripper is simple and does not consist of any state of operation sensors, and therefore is ideal for this testing. The deep ripper will provide a draught load to the tractor using the 3-point linkage system which can be analysed on the CAN Bus. The lift forces applied on the 3-point linkage from the ripper in different field conditions can also be investigated. An image of the deep ripper can be seen in Figure 13.

Figure 13 - Gyral deep ripper fitted to the John Deere 6120R tractor

3.4.3 PTO Mulcher

The second implement chosen for the testing procedure is a PTO mulcher which will provide a load to the tractor in terms of draught as well as PTO load. The reaction of the mulcher on the 3-point linkage in different field conditions can also be investigated. The mulcher used in the data collection can be seen in Figure 14.

Figure 14 - PTO powered mulcher mounted on the back of the UniSQ 6120R

3.4.4 CanCase CAN Bus Communication Device

Connecting to the tractors CAN Bus system using a computer requires a CANcase and a special harness that allows connection to the diagnostics port of the John Deere tractors. The CANcase supplied by John Deere is a Vector CANcaseXL as seen below in Figure 15. The harness used to connect the CANcase to the diagnostic port can be seen in Figure 16. The harness consists of CAN low and high wires for both the vehicle and implement CANs as well as a ground wire that serves as a reference plane for the data messages.

Figure 15 - Vector CANcaseXL that was used to communicate with the CAN Bus on the Joh Deere 6120R

Figure 16 - Diagnostic connector ad harness used for CAN Bus communication

3.4.5 Can Sniff CAN Recording Software

To record the CAN Bus data through the CANcaseXL, CAN Sniff software is required. This program runs and creates a log file from information received via the USB cord from the CANcase. It was provided by John Deere to allow me to collect the data in the field.

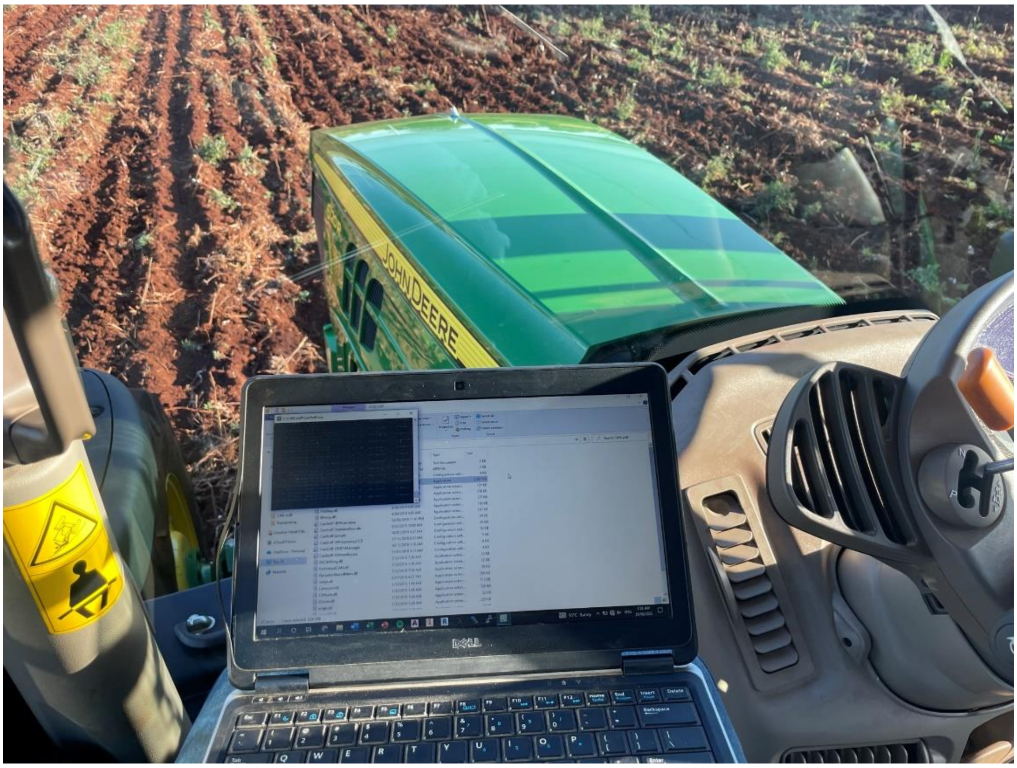

Figure 17 - Recording CAN Bus data using CANsniff software

3.4.6 Test Area

The layout plan as seen in Appendix C shows a map of the rear CAE plot and where the data will be collected. Some of the data was also collected in other areas of the CAE due to changes in field conditions and finding ideal spots to undertake each given test.

3.4.7 Camera recording setup

It was decided that it would be beneficial to record the bridging and shear pin breaking tests using a camera. This would allow the exact time the issue occurred to be recorded and correlated back to the data recorded from the CAN Bus. Using extruded aluminium and t-nuts, a frame was constructed on the back of the deep ripper that a phone could be attached to. This held the phone in a stable position so that videos of the testing could be captured, the camera frame can be seen below in Figure 18 and Figure 19. The chosen placement for the frame allowed the tines of the ripper to be seen as well as in front and behind, an example of the field of view from the camera can be seen in Figure 20.

Figure 18 – Camera frame for videoing the data collection

Figure 20 – Camera frame for videoing the data collection

Figure 19 - Field of view from the camera mounted on the frame

Chapter 4 Results

4.1 Chapter Overview

The purpose of this chapter is to outline the outcomes of the experimental testing process and assess the data obtained. The data collection method is described within the methodology section of this report.

The essential information gathered from the data collection process is presented in Section 4.2 of this chapter. Each section of data also includes a short description including testing set up, observations made during the testing and other issues or notes that are important.

4.2 Testing Results

After analysing the raw data from Matlab, the list of parameters seen below were chosen based on their potential usefulness in determining implement status. General values such as the time and location of the machine were used provide an understanding of what the machine is doing. More advanced parameters such as engine load and fuel usage are the ones analysed to determine their suitability for implement awareness.

- Day
- Hours
- Minutes
- Seconds
- lat_deg
- long_deg
- altitude_m
- course_deg
- pitch_deg
- roll_deg
- speed_kph
- WheelBasedVehicleSpeed_kph
- EngineCoolantTemp_degC
- EngineCrankcasePressure_kPa
- EngineFuelRate_lph
- EngineFuelTemp_degC
- EngineIntercoolerTemp_degC
- EngineOilTemp_degC
- EngineSpeed_rpm
- ReqEngineSpeed
- IVTSetSpeed1F_mps
- RearHitchCurrentPosition_percent
- TRF1_TransmissionOilTemp_degC
- EngPctLoadatCurrSpeed_pct
- RearPTOOutputShaftSpeed

Figure 21 - Parameters exported out of Matlab and into Excel

Once in Excel, these values were graphed and it was concluded that not all of the parameters were proving anything, and therefore 7 (8 including PTO RPM for the PTO testing) parameters were chosen for further analysis. These parameters include:

- Speed
- Wheel-based speed
- Engine RPM
- Engine coolant temperature
- Engine fuel rate
- Engine % load
- Rear hitch height
- Rear PTO RPM

These seven parameters were plotted together on the same graph for each of the tests whereby data was collected. These graphs can be found in Appendices D through to N. It is important to note that the Engine RPM being a large number was graphed on a secondary y-axis to provide a reasonable resolution for the remaining parameters which were graphed on the primary vertical axis. All of the parameters are graphed against a progressive time value in seconds that starts when the data recording was commenced. Some of the parameters such as the speed and wheel-based speed are challenging to gauge when graphed on this scaled axis and so for clearer investigation, the seven parameters were graphed on their own.

The mean and standard deviation of the base run data was found for each of the three implements for their respective speeds and operating depths. The values 3 standard deviations above and below the mean were also found to provide a confidence window that 95% of the data should fall within. This information was only found on the base run data and then utilised in each respective test to provide a baseline reference.

The graphs for the individual parameters also contain the mean and ± 3SD values for their respective base run to provide a baseline that can be referenced between tests. All of the individual graphs can be seen in Appendices D through N for each mode of failure and operating speed and depth.

After graphing the seven parameters individually, five were chosen to be further analysed. Those chosen include percentage engine load, speed, engine fuel rate, rear hitch height and engine RPM.

Using these refined parameters, the mean and variance can be found for each test prior to and after the issue has occurred. The differences in the averages between the initial operating state and the final operating state can be found to provide a value of the amount of change or each parameter in the event of an issue occurring. The difference between the variances is also found as another measure of change of operating conditions.

4.2.1 No Implement

4.2.1.1 Base run

3kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 3kph no implement testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	29.942	3.056	7.191	2.957	84.741	92.020	1899.969
Std Dev	1.337	0.052	0.382	0.012	0.395	0.151	1.544
3 Std Dev	4.012	0.155	1.147	0.036	1.186	0.454	4.633
Mean + 3SD	33.954	3.212	8.338	2.993	85.927	92.474	1904.602
Mean - 3SD	25.930	2.901	6.044	2.922	83.554	91.566	1895.336

5kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 5kph no implement testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	34.423	5.103	8.514	4.952	84.000	92.027	1900.031
Std Dev	1.528	0.094	0.460	0.026	0.000	0.178	2.389
3 Std Dev	4.583	0.281	1.380	0.077	0.000	0.533	7.168
Mean + 3SD	39.006	5.384	9.894	5.029	84.000	92.560	1907.198
Mean - 3SD	29.840	4.822	7.133	4.874	84.000	91.494	1892.863

10kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 10kph no implement testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	49.005	10.160	12.589	9.918	76.298	92.000	1900.259
Std Dev	3.908	0.280	0.860	0.218	1.257	0.000	6.509
3 Std Dev	11.723	0.840	2.580	0.654	3.771	0.000	19.526
Mean + 3SD	60.728	10.999	15.169	10.572	80.070	92.000	1919.785
Mean - 3SD	37.282	9.320	10.009	9.265	72.527	92.000	1880.733

4.2.1.2 Transporting

The start and end cells are chosen based on when the actual testing process began and finished as the start of the recording isn't necessarily when the tractor was in its operating state. These values are slightly different for each table and therefore adjusted values can be seen.

3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 1 to 787 as seen by the start and end cell values. These values are shown for each of the 5 parameters. It can be seen that the variance within the testing period was not very high.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	1	787	32.959	9.820
Speed			3.056	0.069
Engine Fuel Rate			8.194	5.170
Rear Hitch %			92.175	0.194
Engine RPM			1900.000	0.159

5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 1 to 419 as seen by the start and end cell values. These values are shown for each of the 5 parameters. Very little variance can be seen from the data as seen in the table below.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	1	419	35.857	6.301
Speed			5.090	0.134
Engine Fuel Rate			8.951	2.223
Rear Hitch %			93.200	0.000
Engine RPM			1900.060	0.330

10kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 40 to 212 as seen by the start and end cell values. These values are shown for each of the 5 parameters. There is a rather large variation in the engine load throughout this test, due to a varying load, it is also expected that the fuel usage rate has some variability as seen below.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	40	212	44.002	35.422
Speed			10.128	0.185
Engine Fuel Rate			11.472	17.355
Rear Hitch %			93.013	0.204
Engine RPM			1899.855	3.415

4.2.2 3PL Deep Ripper

4.2.2.1 Base run

350mm - 3kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 350mm depth of cut, 3kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	56.172	2.507	14.709	2.878	87.206	22.236	1899.962
Std Dev	3.243	0.111	0.753	0.038	1.966	1.503	3.928
3 Std Dev	9.729	0.333	2.259	0.114	5.898	4.509	11.783
Mean + 3SD	65.901	2.841	16.968	2.992	93.104	26.745	1911.745
Mean - 3SD	46.443	2.174	12.450	2.763	81.307	17.727	1888.178

350mm - 5kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 350mm depth of cut, 5kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	68.326	4.766	17.503	4.954	85.122	26.195	1900.009
Std Dev	4.018	0.111	0.897	0.023	1.344	1.667	6.765
3 Std Dev	12.054	0.334	2.690	0.068	4.031	5.002	20.296
Mean + 3SD	80.380	5.101	20.193	5.022	89.153	31.197	1920.305
Mean - 3SD	56.271	4.432	14.814	4.885	81.091	21.194	1879.713

300mm – 3 kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 300mm depth of cut, 3kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	44.001	2.988	11.507	2.959	88.186	31.124	1900.053
Std Dev	2.803	0.063	0.829	0.029	0.483	2.155	4.229
3 Std Dev	8.409	0.188	2.486	0.088	1.450	6.465	12.688
Mean + 3SD	52.410	3.176	13.993	3.047	89.636	37.589	1912.741
Mean - 3SD	35.592	2.800	9.022	2.872	86.736	24.659	1887.365

300mm – 5kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 300mm depth of cut, 5kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	50.797	5.084	13.358	4.951	87.588	34.309	1899.934
Std Dev	3.320	0.080	0.779	0.026	1.052	1.288	7.249
3 Std Dev	9.960	0.240	2.338	0.079	3.155	3.865	21.748
Mean + 3SD	60.758	5.323	15.696	5.030	90.743	38.175	1921.682
Mean - 3SD	40.837	4.844	11.020	4.871	84.432	30.444	1878.186

200mm – 3kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 200mm depth of cut, 3kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	34.867	3.115	8.627	2.959	87.677	42.481	1900.015
Std Dev	1.520	0.047	0.452	0.025	0.623	1.346	2.419
3 Std Dev	4.560	0.140	1.355	0.076	1.870	4.038	7.256
Mean + 3SD	39.427	3.255	9.982	3.035	89.547	46.520	1907.270
Mean - 3SD	30.308	2.975	7.272	2.882	85.807	38.443	1892.759

200mm – 5kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 200mm depth of cut, 5kph 3PL deep ripper testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM
Mean	44.218	5.148	11.603	4.954	84.496	40.605	1899.950
Std Dev	2.834	0.076	0.809	0.019	0.968	1.486	5.880
3 Std Dev	8.503	0.229	2.428	0.057	2.904	4.457	17.640
Mean + 3SD	52.721	5.377	14.031	5.011	87.400	45.063	1917.590
Mean - 3SD	35.715	4.919	9.175	4.898	81.592	36.148	1882.310

4.2.2.2 Ripper shank shear pin breaking

Single point analysis was completed for this operating condition as there was no significant evidence of a change in operating state during the test and therefore determining how much the whole data set varied will be more useful.

350mm – 3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 23 to 404 as seen by the start and end cell values. These values are shown for each of the 5 parameters. Reasonable variation is evident within this test, however mostly in the rear hitch height and engine load.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	23	404	44.464	14.990
Speed			2.922	0.185
Engine Fuel Rate			11.664	4.898
Rear Hitch %			19.400	14.200
Engine RPM			1900.098	1.078

350mm – 3kph – 2

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 57 to 187 as seen by the start and end cell values. These values are shown for each of the 5 parameters. There is a large amount of variance of engine load in this test as seen in the table below, the rear hitch height is also variable throughout the test.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	57	187	50.056	53.426
Speed			2.914	0.700
Engine Fuel Rate			12.782	10.724
Rear Hitch %			23.025	35.928
Engine RPM			1899.918	4.318

350mm – 5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 23 to 265 as seen by the start and end cell values. These values are shown for each of the 5 parameters. The main variation in this test is the engine load which is approximately 33%.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	23	265	60.634	33.413
Speed			4.812	2.018
Engine Fuel Rate			15.752	6.519
Rear Hitch %			21.538	12.120
Engine RPM			1900.087	3.113

350mm – 5kph – 2

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 20 to 89 as seen by the start and end cell values. These values are shown for each of the 5 parameters. There is a very large variation of the engine load and rear hitch height in this test, graphics of this variation can be seen in Appendix G to provide a better understanding of what is occurring.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	20	89	60.810	78.084
Speed			4.751	2.302
Engine Fuel Rate			15.794	14.613
Rear Hitch %			20.712	41.193
Engine RPM			1899.511	11.880

350mm – 5kph – half cut pin

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 23 to 99 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	23	99	60.838	57.049
Speed			4.920	0.349
Engine Fuel Rate			15.793	11.039
Rear Hitch %			20.039	28.207
Engine RPM			1900.805	7.745

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 23 to 109 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	23	109	43.399	18.524
Speed			3.021	0.261
Engine Fuel Rate			11.301	4.027
Rear Hitch %			32.593	10.582
Engine RPM			1900.541	1.719

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 38 to 109 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	38	109	49.695	221.929
Speed			3.796	35.178
Engine Fuel Rate			12.760	53.040
Rear Hitch %			30.025	19.681
Engine RPM			1899.616	11.894

200mm – 3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 38 to 130 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	38	130	35.814	21.502
Speed			3.155	26.578
Engine Fuel Rate			8.970	8.182
Rear Hitch %			34.525	96.846
Engine RPM			1900.366	1.489

200mm – 5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 8 to 101 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	8	101	40.547	54.527
Speed			4.673	8.839
Engine Fuel Rate			10.583	11.722
Rear Hitch %			37.476	15.762
Engine RPM			1900.013	3.992

4.2.2.3 Ripper digging in too far

Double point analysis using data from prior to the issue occurring as well as after was implemented for this data as there is a distinct change in operating parameters that allows when the issue occurred to be picked. This method will allow a difference in the mean and variance to be found for the data before and after the issue providing a greater understanding of whether the parameters can be used for implement awareness.

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 47 to 468 for prior to the issue occurring, and then again after the issue from 487 to 929. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	47	468	41.590	17.452	487	929	58.591	34.334	40.88	16.882
Speed			2.999	0.124			2.358	2.778	-21.36	2.654
Engine Fuel Rate			10.791	5.682			15.268	6.877	41.48	1.195
Rear Hitch %			33.025	10.023			23.512	11.720	-28.81	1.697
Engine RPM			1899.816	1.034			1900.055	0.734	0.01	0.300

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 21 to 256 for prior to the issue occurring, and then again after the issue from 286 to 562. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	21	256	60.043	32.026	286	562	94.654	33.060	57.64	1.034
Speed			4.938	0.230			3.424	18.515	-30.67	18.286
Engine Fuel Rate			15.615	6.138			22.582	9.841	44.62	3.703
Rear Hitch %			31.796	8.092			22.176	23.167	-30.26	15.075
Engine RPM			1899.851	3.255			1934.151	189.468	1.81	186.212

200mm – 3kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 86 to 445 for prior to the issue occurring, and then again after the issue from 463 to 847. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	86	445	35.340	6.538	463	847	41.951	17.597	18.71	11.059
Speed			3.089	0.076			2.987	0.098	-3.30	0.021
Engine Fuel Rate			8.818	2.326			10.916	6.023	23.79	3.697
Rear Hitch %			40.614	2.531			31.581	7.727	-22.24	5.196
Engine RPM			1900.043	0.452			1900.126	0.941	0.00	0.489

200mm – 5kph

The following table shows the mean and percentage variance relative to the mean based upon the chosen operating period of 28 to 300 for prior to the issue occurring, and then again after the issue from 314 to 478. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	28	300	46.360	22.430	314	478	68.926	64.934	48.67	42.504
Speed			5.148	0.186			4.720	1.431	-8.31	1.245
Engine Fuel Rate			12.182	6.040			17.596	12.777	44.45	6.737
Rear Hitch %			39.955	2.551			27.423	7.683	-31.36	5.132
Engine RPM			1900.103	2.673			1900.558	2.154	0.02	0.520

4.2.2.4 Bridging across tines

Single point analysis was completed for this operating condition as there was no significant evidence of a change in operating state during the test and therefore determining how much the whole data set varied will be more useful.

350mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 3kph operating conditions based upon the chosen operating period of 39 to 157 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	39	157	39.255	23.401
Speed			2.964	0.695
Engine Fuel Rate			10.044	8.204
Rear Hitch %			18.519	27.574
Engine RPM			1879.241	151.355

350mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 5kph operating conditions based upon the chosen operating period of 61 to 167 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	61	167	48.641	96.187
Speed			4.488	12.454
Engine Fuel Rate			12.166	55.478
Rear Hitch %			18.732	22.696
Engine RPM			1763.026	2160.340

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 3kph operating conditions based upon the chosen operating period of 76 to 234 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	76	234	34.928	30.772
Speed			3.053	0.834
Engine Fuel Rate			10.168	5.873
Rear Hitch %			29.732	5.131
Engine RPM			1882.112	254.598

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 5kph operating conditions based upon the chosen operating period of 53 to 149 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	53	149	34.768	45.477
Speed			4.302	1.938
Engine Fuel Rate			8.381	16.375
Rear Hitch %			32.159	49.199
Engine RPM			1674.139	221.260

200mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 3kph operating conditions based upon the chosen operating period of 23 to 181 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	23	181	33.571	19.716
Speed			3.099	0.352
Engine Fuel Rate			8.242	7.391
Rear Hitch %			39.329	168.689
Engine RPM			1900.142	1.390

200mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 5kph operating conditions based upon the chosen operating period of 55 to 194 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	55	194	28.960	52.250
Speed			3.346	6.994
Engine Fuel Rate			6.687	25.260
Rear Hitch %			40.193	158.219
Engine RPM			1582.297	945.960

4.2.2.5 Ripper not digging in far enough

Double point analysis using data from prior to the issue occurring as well as after was implemented for this data as there is a distinct change in operating parameters that allows when the issue occurred to be picked. This method will allow a difference in the mean and variance to be found for the data before and after the issue providing a greater understanding of whether the parameters can be used for implement awareness.

350mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 3500mm and 3kph operating conditions based upon the chosen operating period of 48 to 480 for prior to the issue occurring, and then again after the issue from 500 to 871. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	48	480	62.336	28.342	500	871	43.779	49.983	-29.77	21.641
Speed			2.518	2.461			2.995	0.412	18.97	2.049
Engine Fuel Rate			16.250	5.694			11.471	14.689	-29.41	8.995
Rear Hitch %			16.434	35.570			30.000	0.000	82.55	35.570
Engine RPM			1899.890	2.089			1899.856	1.404	0.00	0.685

350mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 5kph operating conditions based upon the chosen operating period of 33 to 308 for prior to the issue occurring, and then again after the issue from 338 to 499. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	33	308	75.752	19.271	338	499	56.044	47.235	-26.02	27.965
Speed			4.427	3.511			4.976	0.222	12.39	3.289
Engine Fuel Rate			19.090	4.816			14.693	9.624	-23.03	4.807
Rear Hitch %			18.831	22.332			29.199	12.372	55.06	9.960
Engine RPM			1883.631	324.988			1900.421	3.524	0.89	321.465

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 3kph operating conditions based upon the chosen operating period of 48 to 373 for prior to the issue occurring, and then again after the issue from 418 to 751. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	48	373	39.882	13.792	418	751	37.097	3.260	-6.98	10.532
Speed			3.054	0.147			3.128	0.108	2.44	0.039
Engine Fuel Rate			10.214	5.163			9.337	1.064	-8.59	4.099
Rear Hitch %			32.055	7.041			40.842	2.029	27.41	5.012
Engine RPM			1899.934	0.663			1899.957	0.227	0.00	0.437

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 5kph operating conditions based upon the chosen operating period of 18 to 258 for prior to the issue occurring, and then again after the issue from 268 to 500. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	18	258	52.159	25.555	268	500	42.959	22.224	-17.64	3.331
Speed			5.032	1.818			5.190	0.162	3.15	1.656
Engine Fuel Rate			13.742	5.745			11.196	7.388	-18.53	1.643
Rear Hitch %			32.257	7.596			39.773	3.728	23.30	3.868
Engine RPM			1899.816	3.328			1899.887	2.061	0.00	1.268

4.2.2.6 Failing to lift the 3PL prior to headland execution

Single point analysis was completed for this operating condition as there was no significant evidence of a change in operating state during the test and therefore determining how much the whole data set varied will be more useful.

350mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 3kph operating conditions based upon the chosen operating period of 1 to 205 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	1	205	43.933	17.066
Speed			2.969	0.226
Engine Fuel Rate			11.514	5.596
Rear Hitch %			23.665	8.393
Engine RPM			1900.120	1.420

350mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 5kph operating conditions based upon the chosen operating period of 1 to 120 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	1	120	62.181	38.045
Speed			4.719	3.993
Engine Fuel Rate			16.103	7.524
Rear Hitch %			26.108	14.319
Engine RPM			1899.997	4.534

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 3kph operating conditions based upon the chosen operating period of 33 to 220 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	33	220	38.268	11.406
Speed			3.052	0.163
Engine Fuel Rate			9.710	4.092
Rear Hitch %			31.832	15.023
Engine RPM			1900.107	0.582

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 5kph operating conditions based upon the chosen operating period of 14 to 141 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	14	141	63.343	24.723
Speed			4.823	0.334
Engine Fuel Rate			16.358	4.643
Rear Hitch %			28.067	23.455
Engine RPM			1899.644	3.750

200mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 3kph operating conditions based upon the chosen operating period of 1 to 250 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	1	250	33.849	7.100
Speed			3.100	0.102
Engine Fuel Rate			8.359	2.419
Rear Hitch %			39.686	6.754
Engine RPM			1900.125	0.347

200mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 5kph operating conditions based upon the chosen operating period of 8 to 120 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	8	120	40.932	29.332
Speed			5.154	0.213
Engine Fuel Rate			10.572	10.189
Rear Hitch %			39.892	3.569
Engine RPM			1900.147	3.159

4.2.2.7 Travelling through washouts

Double point analysis using data from prior to the error as well as the complete data set was completed for these operating conditions. This is due to the change in operating state being temporary and eventually returning back to an average status.

350mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 3kph operating conditions based upon the chosen operating period of 22 to 49 for prior to the issue occurring, and then again for the whole test from 22 to 131. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	22	49	37.251	19.459	22	131	40.237	86.142	8.02	66.683
Speed			2.952	0.256			2.943	4.573	-0.29	4.317
Engine Fuel Rate			9.441	8.214			10.296	28.444	9.06	20.230
Rear Hitch %			21.536	5.496			27.401	326.844	27.23	321.347
Engine RPM			1900.105	2.205			1899.990	6.755	-0.01	4.550

350mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 350mm and 5kph operating conditions based upon the chosen operating period of 13 to 36 for prior to the issue occurring, and then again for the whole test from 13 to 88. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	13	36	47.752	72.550	13	88	51.881	215.507	8.65	142.957
Speed			4.939	0.492			4.940	7.981	0.03	7.490
Engine Fuel Rate			12.517	19.134			13.462	52.855	7.55	33.721
Rear Hitch %			21.720	6.781			27.313	349.193	25.75	342.412
Engine RPM			1898.382	14.931			1899.216	19.079	0.04	4.148

300mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 3kph operating conditions based upon the chosen operating period of 14 to 52 for prior to the issue occurring, and then again for the whole test from 14 to 121. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	14	52	29.324	24.982	14	121	32.073	54.664	9.38	29.683
Speed			3.041	0.472			3.057	3.657	0.52	3.185
Engine Fuel Rate			6.986	7.550			7.836	19.708	12.17	12.159
Rear Hitch %			35.501	14.440			39.200	154.484	10.42	140.044
Engine RPM			1898.985	1.959			1899.764	2.019	0.04	0.059

300mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 300mm and 5kph operating conditions based upon the chosen operating period of 15 to 38 for prior to the issue occurring, and then again for the whole test from 15 to 79. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	15	38	35.089	250.806	15	79	38.479	224.372	9.66	26.435
Speed			4.789	4.428			4.980	7.901	3.99	3.473
Engine Fuel Rate			8.663	79.188			9.638	72.444	11.26	6.743
Rear Hitch %			36.579	6.969			39.585	119.145	8.22	112.175
Engine RPM			1848.929	449.539			1881.497	204.905	1.76	244.634

200mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 3kph operating conditions based upon the chosen operating period of 2 to 17 for prior to the issue occurring, and then again for the whole test from 2 to 79. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	2	17	28.530	12.367	2	79	32.194	47.219	12.84	34.851
Speed			2.996	0.427			3.060	5.412	2.11	4.984
Engine Fuel Rate			6.807	2.899			7.890	16.392	15.90	13.493
Rear Hitch %			44.974	1.008			48.967	135.599	8.88	134.590
Engine RPM			1899.653	1.481			1899.943	1.764	0.02	0.283

200mm – 5kph

The following table shows the mean and percentage variance relative to the mean for 200mm and 5kph operating conditions based upon the chosen operating period of 25 to 40 for prior to the issue occurring, and then again for the whole test from 25 to 78. These values are shown for each of the 5 parameters. The percentage difference between the means and variance can also be seen in the last two columns.

	Start Cell	End Cell	Mean	Variance	Start Cell	End Cell	Mean	Variance	% diff	Variance Difference
Engine % Load	25	40	35.583	172.838	25	78	37.997	257.631	6.78	84.792
Speed			4.924	1.227			5.094	7.347	3.45	6.120
Engine Fuel Rate			8.760	39.825			9.524	77.488	8.72	37.663
Rear Hitch %			40.261	1.062			45.533	125.279	13.10	124.216
Engine RPM			1895.445	13.593			1900.207	12.829	0.25	0.764

4.2.3 PTO Powered Mulcher

4.2.3.1 Virgin ground

150mm – 3kph

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 150mm depth of cut, 3kph PTO powered mulcher testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM	Rear PTO RPM
Mean	59.160	3.057	16.691	2.823	85.324	25.935	1960.048	535.458
Std Dev	9.120	0.048	2.421	0.026	0.738	4.982	11.527	9.591
3 Std Dev	27.359	0.143	7.264	0.077	2.214	14.946	34.582	28.774
Mean + 3SD	86.519	3.200	23.954	2.901	87.538	40.882	1994.630	564.233
Mean - 3SD	31.801	2.914	9.427	2.746	83.111	10.989	1925.466	506.684

150mm – 3kph – 2

The following table shows the values for the mean and ± 3SD from the mean for each parameter that are used as a baseline for all of the 150mm depth of cut, 3kph PTO powered mulcher testing data.

	Engine Load	Speed	Engine Fuel Rate	Wheel Based Speed	Coolant temp	Rear hitch %	Engine RPM	Rear PTO RPM
Mean	57.894	3.175	16.326	2.955	88.065	26.062	1959.202	529.576
Std Dev	8.744	0.064	2.268	0.030	1.830	7.138	14.701	56.552
3 Std Dev	26.231	0.192	6.805	0.089	5.490	21.414	44.103	169.655
Mean + 3SD	84.125	3.366	23.131	3.043	93.556	47.476	2003.304	699.231
Mean - 3SD	31.663	2.983	9.522	2.866	82.575	4.648	1915.099	359.920

4.2.3.2 Ripped ground

Single point analysis was completed for these operating conditions as there was no change in operating state during the test and therefore the data needs to be compared back to the baseline data.

150mm – 3kph

The following table shows the mean and percentage variance relative to the mean for 150mm and 3kph operating conditions based upon the chosen operating period of 66 to 750 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	66	750	49.959	32.504
Speed			3.193	0.061
Engine Fuel Rate			14.395	7.396
Rear Hitch %			27.090	5.090
Engine RPM			1960.292	2.394

150mm – 3kph – 2

The following table shows the mean and percentage variance relative to the mean for 150mm and 3kph operating conditions based upon the chosen operating period of 43 to 798 as seen by the start and end cell values. These values are shown for each of the 5 parameters.

	Start Cell	End Cell	Mean	Variance %
Engine % Load	43	798	51.426	45.832
Speed			3.178	0.067
Engine Fuel Rate			14.739	10.708
Rear Hitch %			26.475	5.527
Engine RPM			1959.997	3.528

4.3 Overall Results

All of the results tables were combined together, and a rank was applied to every parameter of every test with 1 being the largest difference in both mean and variance and 5 being the smallest. The sum of all ranks for each parameter was then found as seen in the table below. From the table it can be deducted that the engine % load is the best indicator of an implement issue with the rear hitch height being the next closest indicator. Both engine RPM and engine fuel rate were tied for third most suitable parameter. The speed is clearly not a good indicator of an issue as the tractor is already capable of changing gears and engine RPM to ensure the set speed is maintained at all times.

	Mean	Variance		
Engine % Load	87	68	1	1
Speed	170	161	5	5
Engine Fuel Rate	117	114	4	3
Rear Hitch %	88	82	2	2
Engine RPM	93	135	3	4

Given the majority of testing involved the 3PL, it is probably not a fair assumption to say it is a good indicating parameter for the wide variety of operations that a general tractor would undertake.

Chapter 5 Discussion

5.1 Chapter Overview

This chapter summarises and discusses the work completed within the project and is implications on the outcomes of the project and possible future developmental work.

This work will hopefully be able to be further developed along with industry inputs to reach a state where major agricultural machinery companies see the possibilities of the technology that already exists on their machines.

The testing procedure that was developed to simulate operational field issues, the results found from the testing procedure, as well as some recommendations as to the use of CAN Bus based perception systems in autonomous tractors will be discussed to satisfy the project objectives.

5.2 Achievement of Project Objectives

This research project was completed based around the aim of fulfilling pre-defined project objectives as seen in Chapter 1.3. Keeping these objectives as the main priority of the project allows the specific research question to be answered.

5.2.1 Objective 1 - Develop a test procedure to assess machine perception

The first objective of the research project was to develop a test procedure to simulate various field operational issues that would allow machine perception to be assessed.

Within the literature review, previous physical tractor testing methods were analysed such as the Nebraska Tractor Test developed by the Nebraska Tractor Test Laboratory at the University of Nebraska. While this test does not cover the same exact tests that are required for this project, it provides an appropriate base to develop a testing procedure that can be repeated in a consistent manor. This research project is also a development of the work completed by Torrance (2020) who developed a comparative test procedure for the assessment of autonomous tractor performance. He found that the John Deere 6120R tractor was lacking perception functionality and therefore could not be classified as an autonomous tractor. The work completed by Torrance (2020) also provides an understanding of how to set out a testing procedure which can be built upon for this project.

Through Chapter 2 (Literature Review) in particular Chapter 2.6, investigation was undertaken to determine what simple agricultural implements could be analysed and what issues may occur with these implements. The issues were decided on based upon personal experience and issues that an operator would sense. The purpose of this technology is to take the place of the operator due to its ability to detect issues that are currently sensed by the driver through either sight, sound or feeling. As a result, two basic farming operations, transporting and 3PL deep ripping were chosen as basic implements that do not contain an inbuilt sensor system. Proof of concept testing was also undertaken with a PTO powered mulcher to see if PTO powered machinery could also be monitored with the tractor's inbuilt sensors. Within each operation or implement, a range of operating states have been devised based around sensible and safe operating speeds and depths. Considering the machinery available to carry out the testing was also an essential part in deciding what implements to use. The John Deere 6120R tractor as well as 3PL deep ripper and PTO powered mulcher were borrowed from the University of Southern Queensland. The university also supplied the land on which the data collection process could be undertaken which made the whole process more streamlined.

Some issues that were identified that can occur with a 3PL ripper include the ripper shank shear pin breaking, the ripper digging in too far as a result of change in implement height or ground conditions, bridging across two or more tines creating a bulldozing effect, the ripper not digging in far enough due to hard pans in the soil, failing to lift the 3PL prior to executing the headland manoeuvre and travelling through washouts resulting in a change of the operating depth of the implement. For no implement, a transporting mode of failure was investigated to determine if there is any sense of operation status from the tractor's sensors.

Each mode of failure had a test designed that would replicate the issue in a realistic manor. It is also essential that the testing method is safe and will not cause any harm or damage to the operator or machinery. The tests also had to be repeatable so that the methodology could be utilised on many different tractors and operating conditions. To carry out this data collection for other tractors, it would be important to run the baseline data tests again to allow all of the data to be referenced off a consistent data set.

From this, the testing procedure was designed to be safe, repeatable and replicatory of the real-world modes of failure. The testing procedure can be found in Chapter 3 (Methodology) specifically section 3.3.2.

Overall, the testing method developed provides a broad range of operating states and modes of failure that allow an investigation into whether the sensors that are on the tractor already can be utilised for implement perception.

After completing the data collection, it was obvious that there were a few improvements that could be made to the testing procedure. The bridging test was rather uncontrollable as the board on the ground would often not perch in its required spot to drag the soil along. Improvements could be made to this testing method to make it more repeatable and consistent. Attempting to collect all similar or related data on the same day would also be beneficial as there are multiple environmental changes that will affect how the tractor operates such as soil moisture and ambient temperature.

5.2.2 Objective 2 - Assess the utility and sensitivity of CAN Bus information

The second major objective of the research project was to assess the utility and sensitivity of information exchanged on the tractors CAN Bus for machine perception purposes.

To analyse the information exchanged on the CAN Bus, it is important to understand how the CAN Bus system of modern agricultural machinery works so that data can be collected from various sensors that are already installed on the tractor. It was determined in the methodology chapter (Chapter 3.4.4 and 3.4.5) that using a CANcaseXL and Can Sniff software was the best method of recording CAN Bus data off the John Deere tractor.

After recording the data using the software and hardware provided by John Deere, the data was sent to John Deere in the United States of America for conversion into a useable format. The data was sent back in Matlab format after which specific chosen parameters were exported into Excel for easier graphing and analysis.

The data in Excel was further refined and parameters that did not show any change in operating state were removed. Eventually, seven key parameters were decided upon; engine fuel rate (lph), speed (km/h), wheel-based speed (km/h), engine coolant temperature (degC), rear hitch height (%), engine load (%) and engine speed (RPM). These seven parameters were graphed against the mean and ± 3SD values from the base runs for each speed and operating depth. The mean and variance of each data set was also calculated to allow further refinement of the data to approach a finite answer as to which parameter is the best indicator of a possible issue occurring with the implement. After a ranking process based on the mean and variance values, it can be concluded that the engine % load is the best indicator that an issue has occurred. The second-best parameter is the rear hitch height, however this could be considered a false reading as the majority of tests undertaken revolved around the 3 point linkage and therefore the data may not be representative of drawbar or PTO powered implements. Further testing with these implements would need to be undertaken to ensure correct results. The third best parameter is a tie between engine fuel rate and engine RPM. Based on visual inspection of the graphs, either of these parameters could be suitable.

	Rank
Engine % Load	1
Rear Hitch %	2
Engine Fuel Rate	3
Engine RPM	3
Speed	4

The sensitivity of the chosen parameters is one of the most important parts of determining the feasibility of using the tractors existing sensors to examine the operating status of the implement. While the sensors are evidently sensitive enough to detect some change, the efficiency of their issue detection is left to be questioned. It can be concluded that the sensors are suitable for the job in terms of detecting a change in operating state, however their effectiveness in a system designed to detect operational issues with the implement may be underwhelming.

Further investigation through a wider range of tests and more detailed testing would be required to determine if the sensors are suitable for implement status awareness.

5.2.3 Objective 3 - Recommendations for CAN Bus based perception systems

The third objective for the research project was to develop recommendations for CAN Bus based perception systems that will inform autonomous operations.

After undergoing the data collection process and seeing the data that was obtained from the testing, conclusions can be drawn as to the effectiveness of CAN Bus based implement perception systems. Working through the data analysis and refinement of parameters to find the best suited for the process has shown that there is a large amount of variability within the data. This variability can be attributed to changing field conditions as well as slightly different operating conditions between runs. Changing field conditions is an issue that's always going to exist given the system would ideally use machine learning to understand that an issue has occurred and is resulting in the machine operating outside its standard operating zone. This standard operating zone is going to change across the field with differing soil characteristics and therefore the system would have to be able to adjust so that the chances of detecting an issue are still suitable.

Based on the information gathered within this research project, it can be determined that CAN Bus based perception systems would be suitable for informing autonomous operations, however, in their current state the system would not operate efficiently. Further research needs to be completed to determine how to reduce the noise in the recording system to further increase the control of the system. The majority of the sensors that already are on the tractor are not sensitive enough to detect many of the minor issues that were tested in the data collection. Overall, the system has potential, however, a large amount of work still remains to refine the process to allow smooth consistent data for implement awareness.

5.3 Limitations

The main limitations for this research project were the time available and the data analysis stages.

The project was scaled to suit the available time given the short project timeframe. With more time, the project could be further developed to look at more implements and modes of failure that may occur in the field. While only simple implements were available for this research project, there are a large variety of implements that would benefit from this technology. Testing a range of implements and modes of failure will allow better conclusions to be drawn regarding the ability of the tractors in-built sensors to provide awareness of the operating state of the implement.

The data analysis was undertaken in a basic fashion, however, could be greatly improved by using more statistical methods. The large volume of data also made the analysis process difficult as graphs become crowded, or the number of graphs become too many. Developing an automated process of data analysis is something that would be beneficial if expanding the work into other implements and modes of failure.

The effect of environmental conditions on the results could not be tested due to the limited timeframe of the project. The majority of the data collection was undertaken in July/August and therefore a range of soil moistures and ground conditions couldn't be analysed. Changing these field conditions may have an effect on the accuracy and outcomes of the data and so would be worthwhile testing in future.

Chapter 6 Conclusion

6.1 Chapter Overview

This chapter encapsulates the key findings of the research project as well as presents recommendations based on the results from testing and analysis. Conclusions are made from all portions of the project and recommendations towards further work and the suitability of the tractors sensors for implement awareness.

6.2 Key Findings

The conclusions and key findings that were drawn from this project are summarised below:

- The testing procedure developed for data collection was suitable, however could have been expanded if more time was available. Expanding the testing variable would allow a more accurate response regarding the suitability of CAN Bus based perception systems for autonomous tractors.

- CAN Bus based systems are efficient and allow for easy access to sensor data, however the sensitivity and suitability of each sensor for issue detection is not up to the standard that would be required for implement perception.

- The sensor data is very noisy and therefore determining when an issue has occurred can be very challenging. It would be recommended that data from multiple sensors would be combined together to allow the case to be confirmed prior to setting off an alarm or assuming something has gone wrong.

- Further work and development should be implemented to further analyse the sensors available on the tractor as there is potential in the system, it just needs to be further refined to make it useful.

- Overall, CAN Bus based perception systems are the way of the future as it is efficient and simple to setup when a large number of sensors are installed on a machine such as an autonomous tractor.

- There may be aftermarket sensors that could be retrofitted to the tractor to provide a better understanding of what the implement's operating status is.

6.3 Further Work and Recommendations

After completing this project, the following points are proposed:

- Further develop the testing method and expand the quantity of tests to provide a better understanding of what the sensors are reading when the failures are occurring.

- Develop an analysis software package for the data to reduce the time that is required to receive a result due to the large volume of data that needs to be processed.

- Complete the testing procedure in a variety of soil types and environmental conditions to attempt to gain more of a real world understanding of how the sensors will react to an issue occurring.

- Explore other sensors that could be installed on the tractor to provide a better understanding of the implements operating status.

- Conduct further testing using drawbar and PTO powered implements to understand the suitability of this methodology on a wider range of tractor implement combinations.

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Appendices

Appendix A – Project Specification

ENG4111/ENG4112 Research Report

Project Specification

For: Sam Green

Title: Investigation into implement status awareness for autonomous tractors

Major: Agriculture

Supervisors: Justine Baillie
Craig Baillie

Enrolment: ENG4111 – ONC S1, 2022
ENG4112 – ONC S2, 2022

Project Aim: The aim of this research is to determine if sensory information that is already on a tractors CAN Bus system can provide a sense of machine and implement perception for autonomous applications. Analysis of the collected data from the designed testing procedure will allow conclusions to be drawn about the ability of the tractors sensors to determine the state of operation of the implement.

Program: Version 1, 22nd February 2022

1. Development of literature – investigate existing information regarding collecting CAN Bus data and utilising it to monitor a vehicles operating state. Also look into current testing procedures that could be modified to suit the data to be collected. Identify any gaps or works that can be built upon for this research project.

2. Conduct investigation into the process of data collection from the CAN Bus system of autonomous John Deere tractors.
3. Investigate which data may be useful in determining whether an issue may have occurred with the implement.
4. Secure machinery and site to allow testing to be undertaken safely and when required.
5. Complete the UniSQ WH&S forms to ensure machinery can be operated in a safe manor.
6. Develop an experimental procedure to simulate issues occurring on basic tractor implements that do not have their own sensor systems.
7. Conduct preliminary testing to verify that the data can be collected and the testing procedure will be suitable, then if necessary modify the testing procedure to ensure the correct data is collected.
8. Perform experiment procedure to capture data.
9. Process and evaluate the data collected in the experiments.
10. Present the findings of the experimental procedure and develop recommendations towards CAN Bus based perception systems in autonomous tractors.

Appendix B – Data collection testing matrix

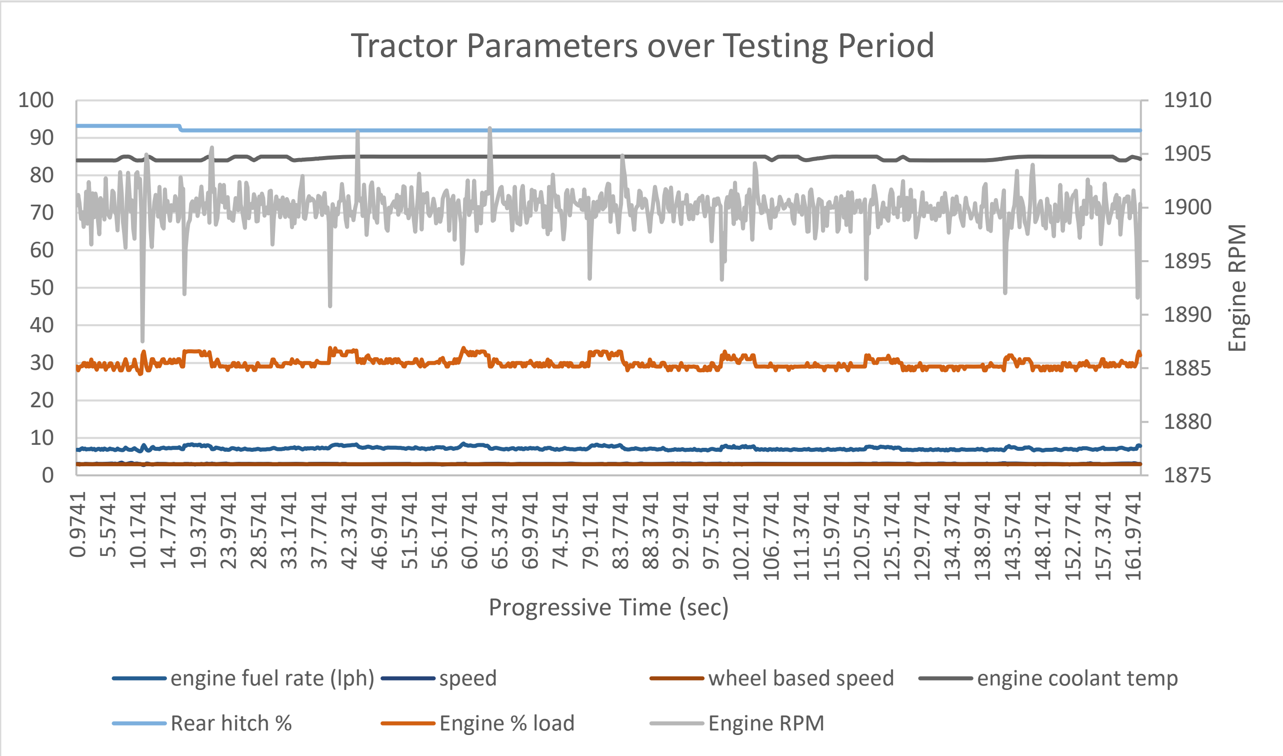
			40%	30%	20%		40%	30%	20%				
		3 km/h				5 km/h				10 km/h			
	Operating Depth	N/A	200mm	300 mm	350 mm	N/A	200mm	300 mm	350 mm	N/A	200mm	300 mm	350 mm
No Implement	Base run on virgin ground												
	Transporting												
3 Point Linkage Deep Ripper	Base run												
	Ripper shank breaking off												
	Ripper digging in too far												
	Bridging occurred across tines												
	Ripper is not digging in far enough												
	Failing to lift implement prior to headland												
	Failing to change 3PL height when going through a washout												

			150mm										
PTO Powered Mulcher	Base run - virgin ground												
	Operating in pre-ripped ground												

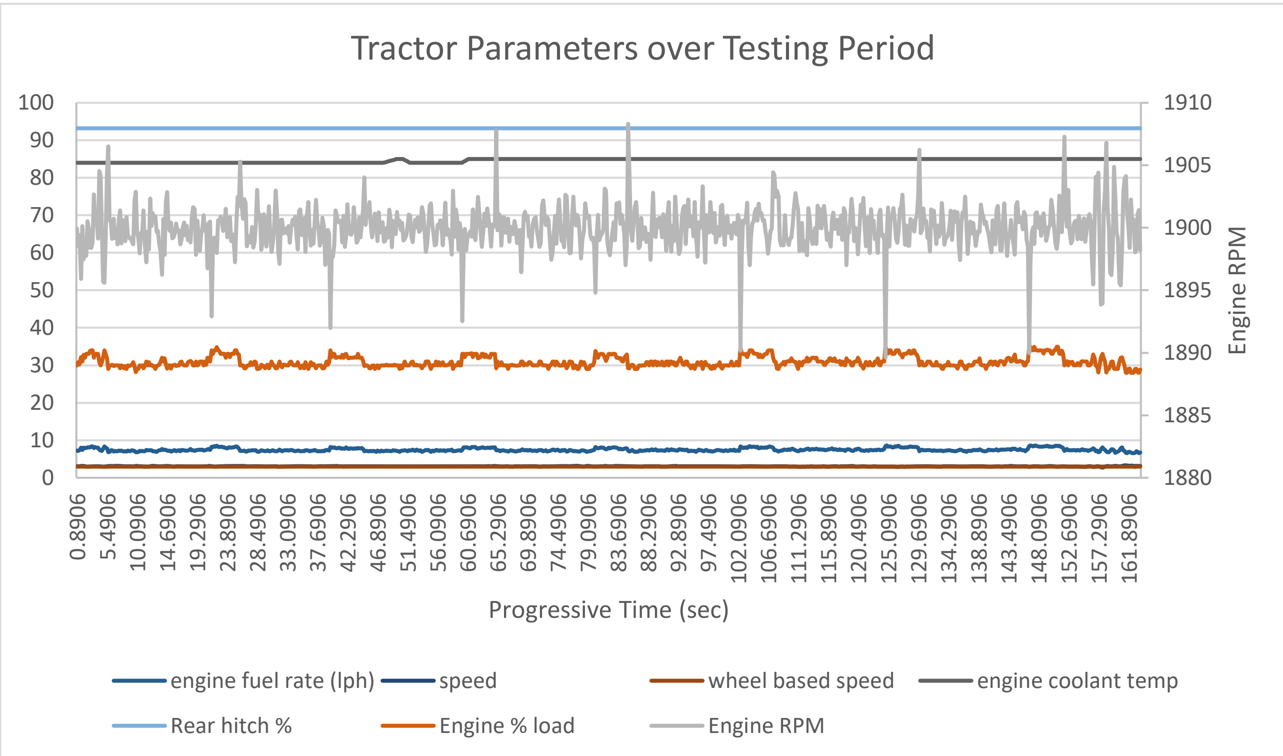
Appendix C – Map of data collection area

Appendix D – No Implement – Base Run Data

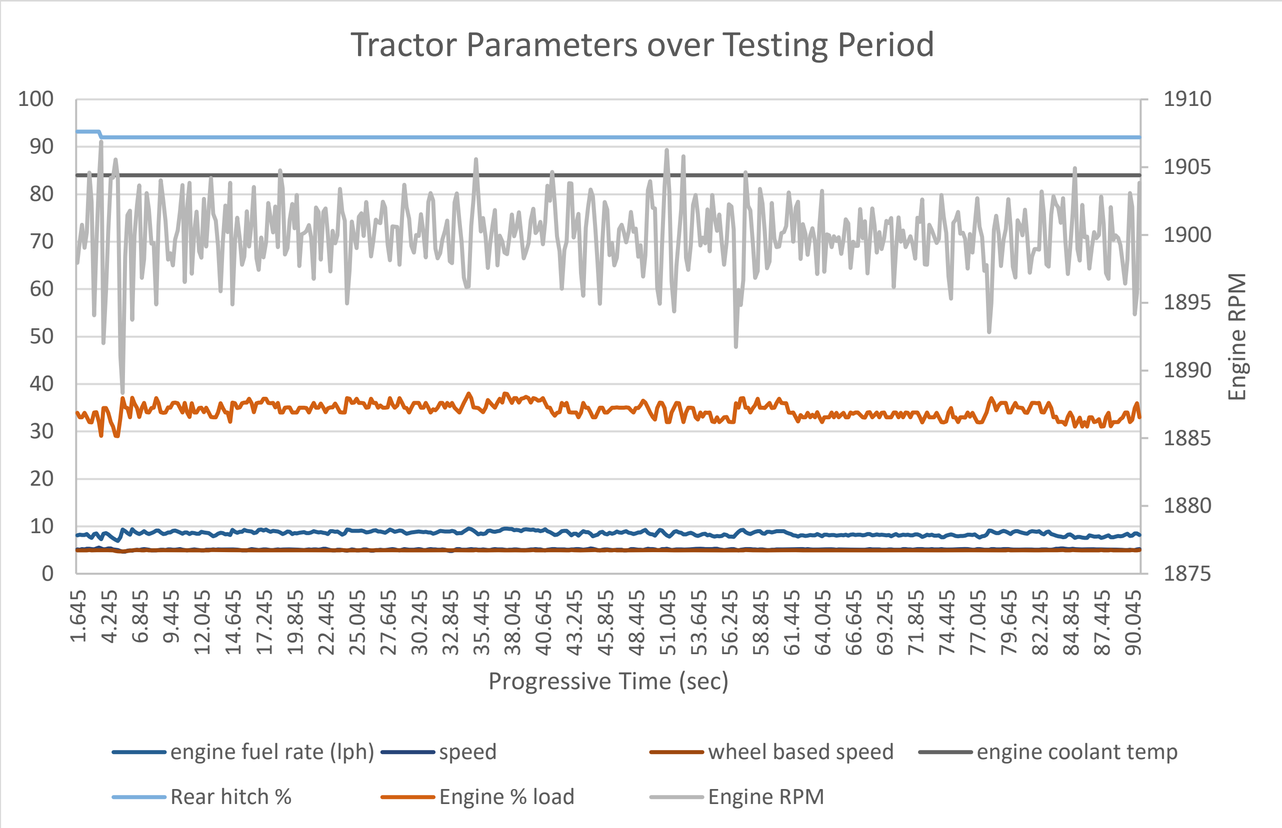
3kph



3kph – 2

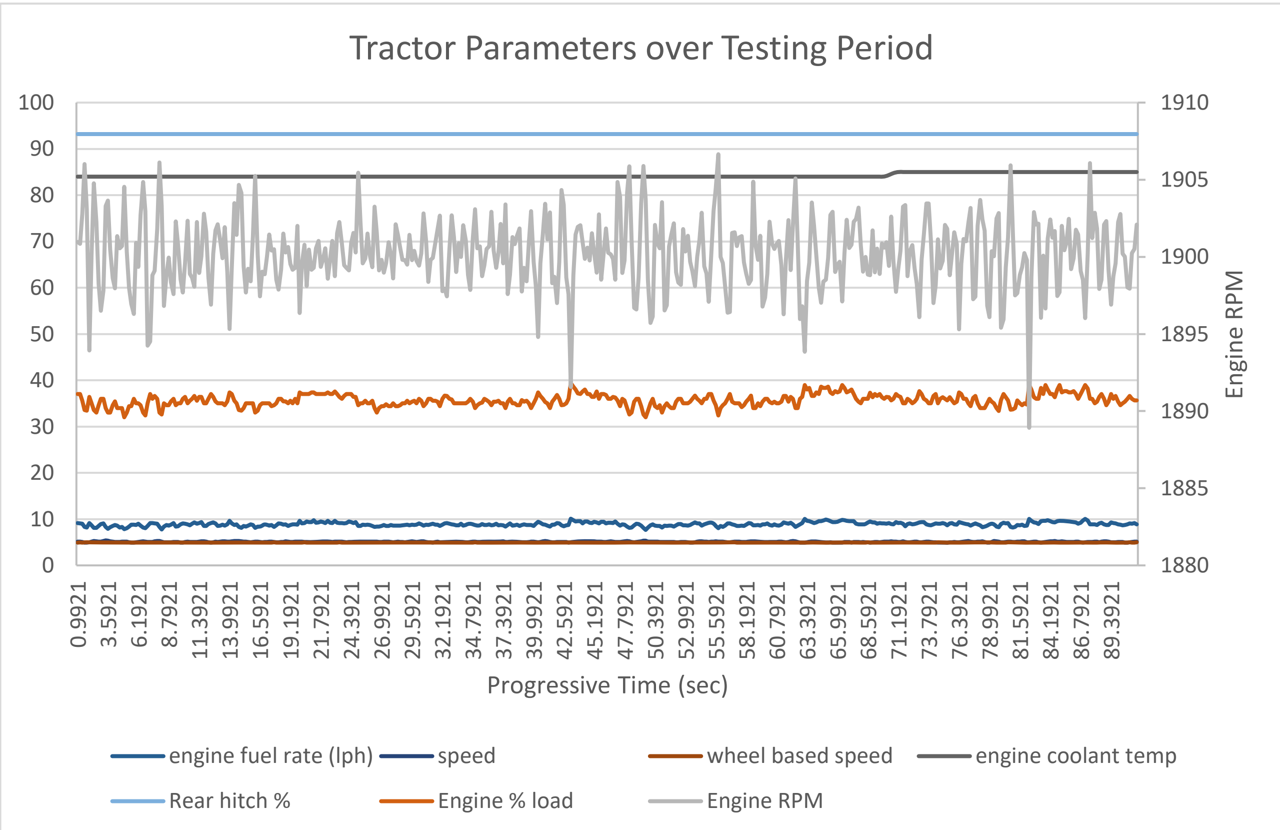


5kph



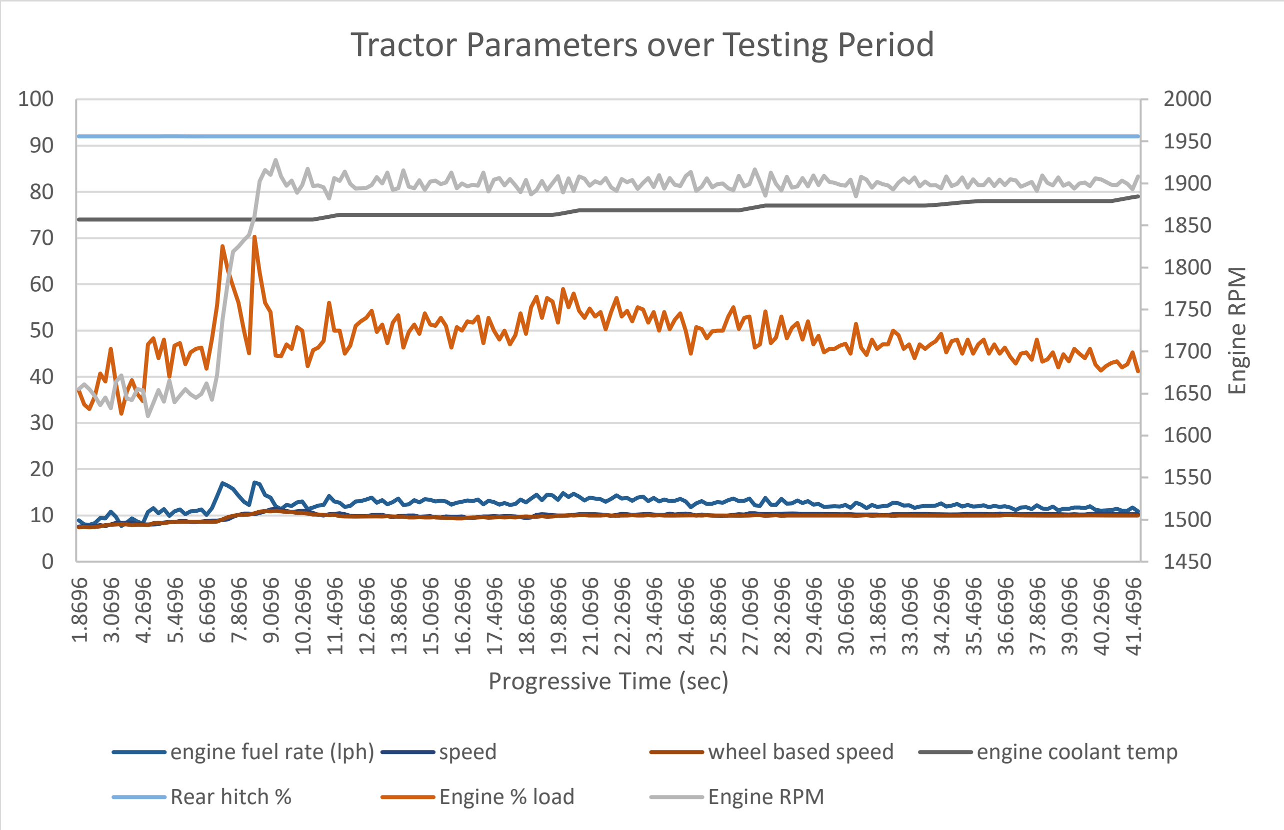
Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1910
1905
1900
1895
1890
1885
1880
1875
Engine RPM
1.645 4.245 6.845 9.445 12.045 14.645 17.245 19.845 22.445 25.045 27.645 30.245 32.845 35.445 38.045 40.645 43.245 45.845 48.445 51.045 53.645 56.245 58.845 61.445 64.045 66.645 69.245 71.845 74.445 77.045 79.645 82.245 84.845 87.445 90.045
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

5kph – 2

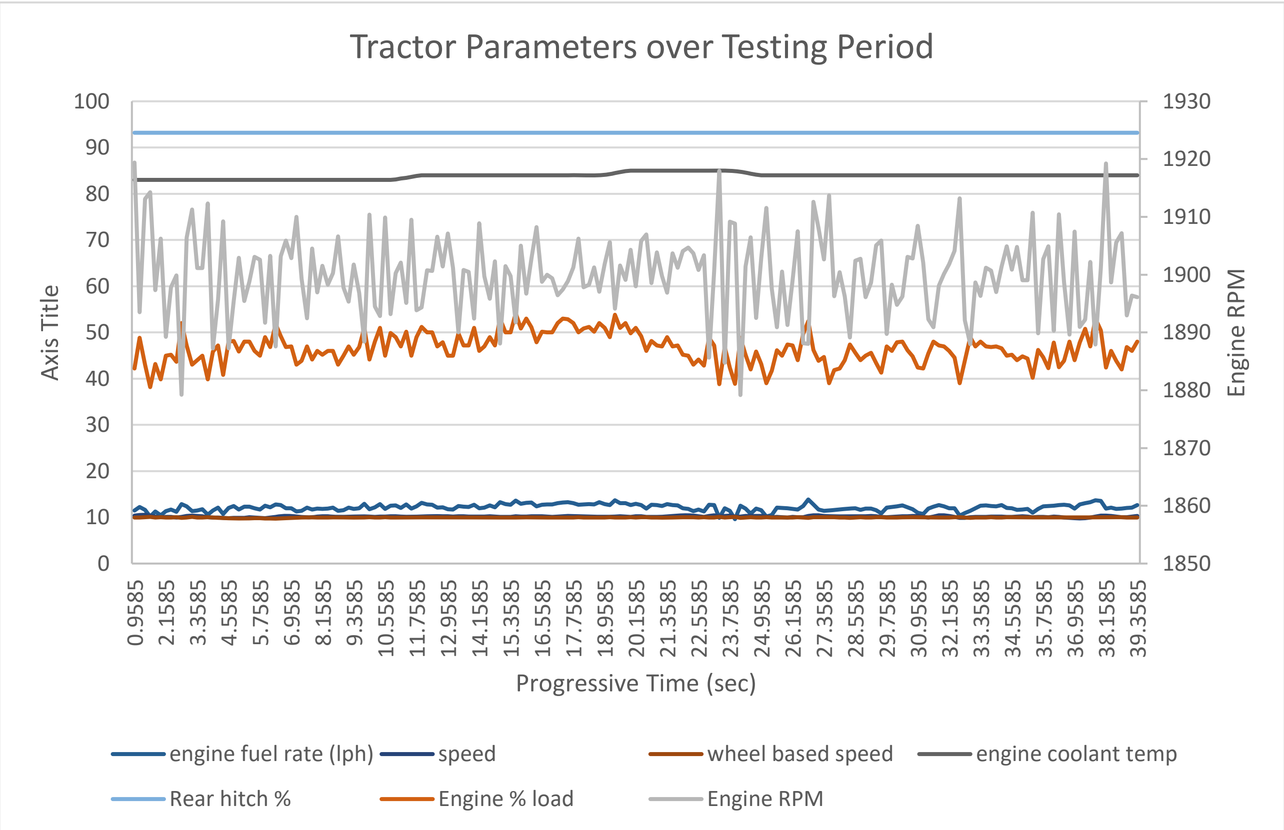


Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1910
1905
1900
1895
1890
1885
1880
Engine RPM
0.9921 3.5921 6.1921 8.7921 11.3921 13.9921 16.5921 19.1921 21.7921 24.3921 26.9921 29.5921 32.1921 34.7921 37.3921 39.9921 42.5921 45.1921 47.7921 50.3921 52.9921 55.5921 58.1921 60.7921 63.3921 65.9921 68.5921 71.1921 73.7921 76.3921 78.9921 81.5921 84.1921 86.7921 89.3921
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

10kph

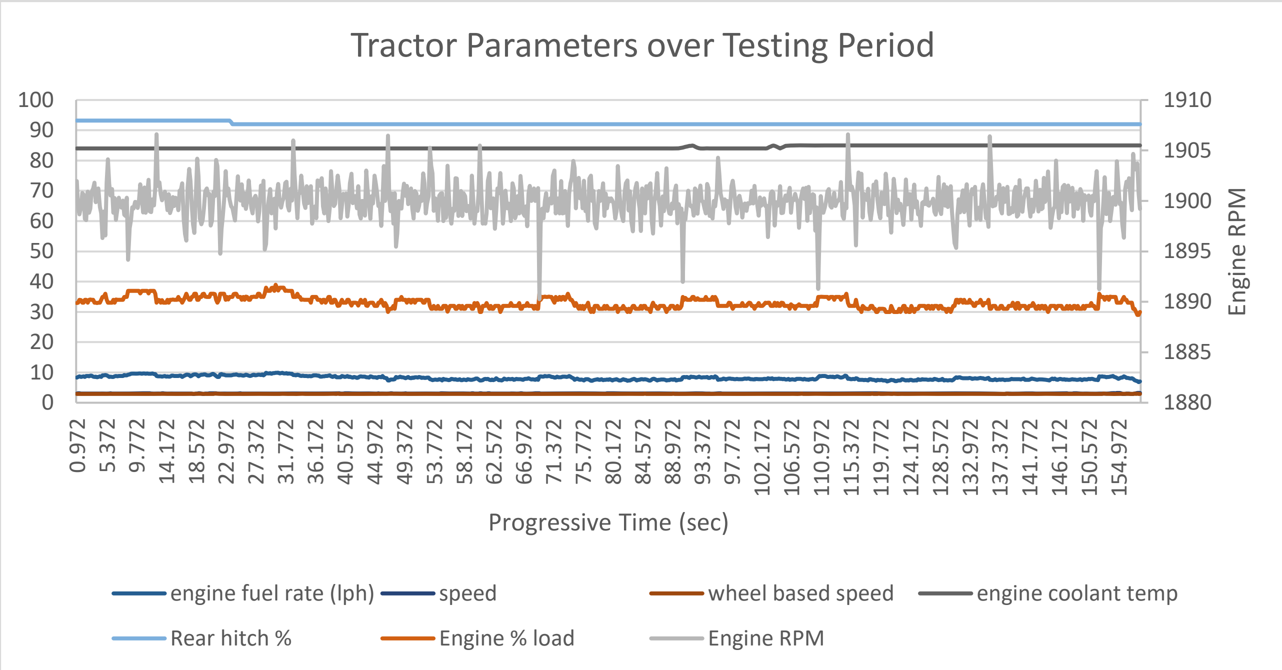


10kph - 2

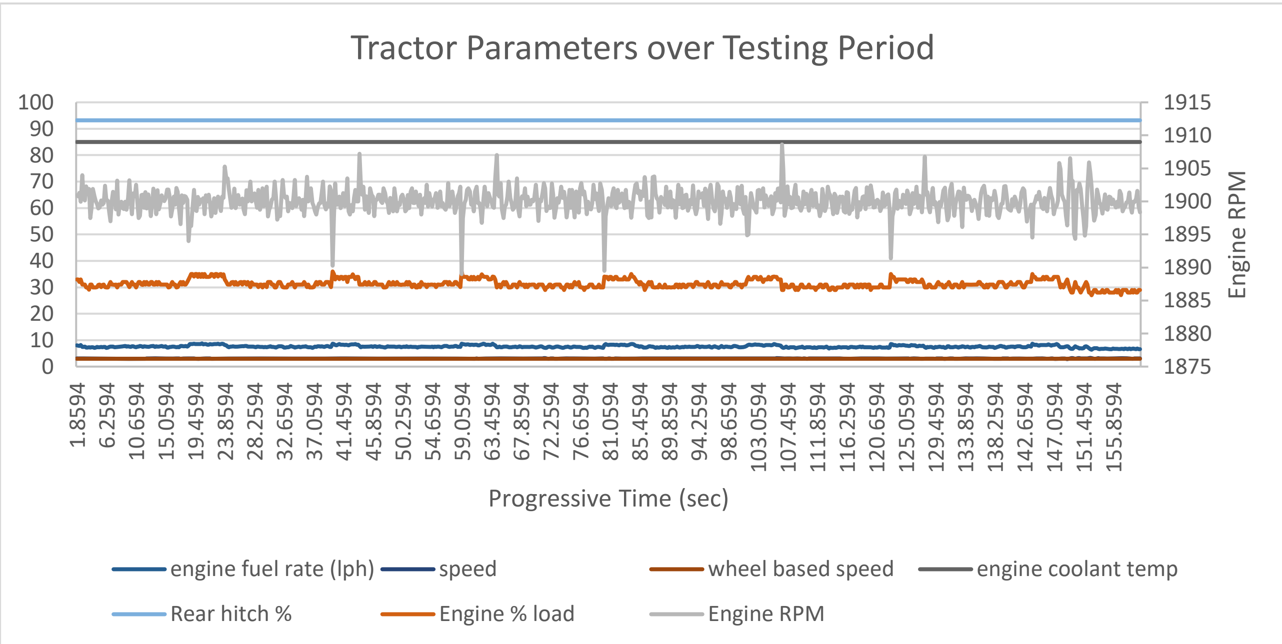


Appendix E – No Implement – Transporting data

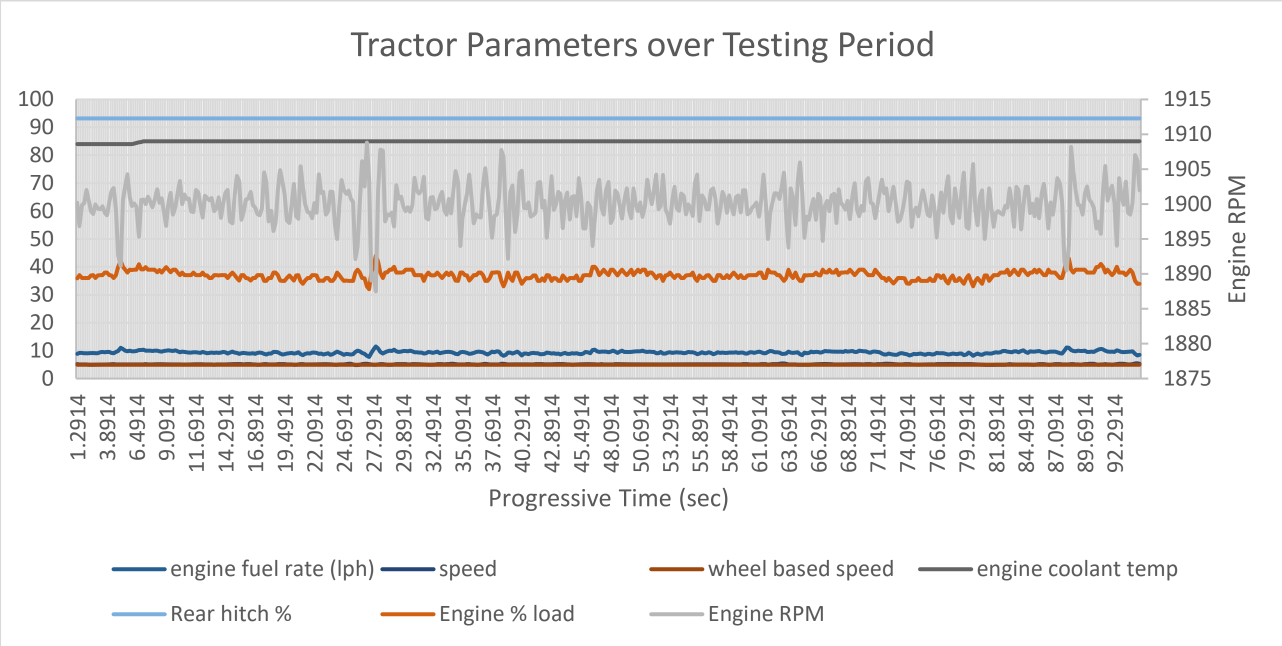
3kph



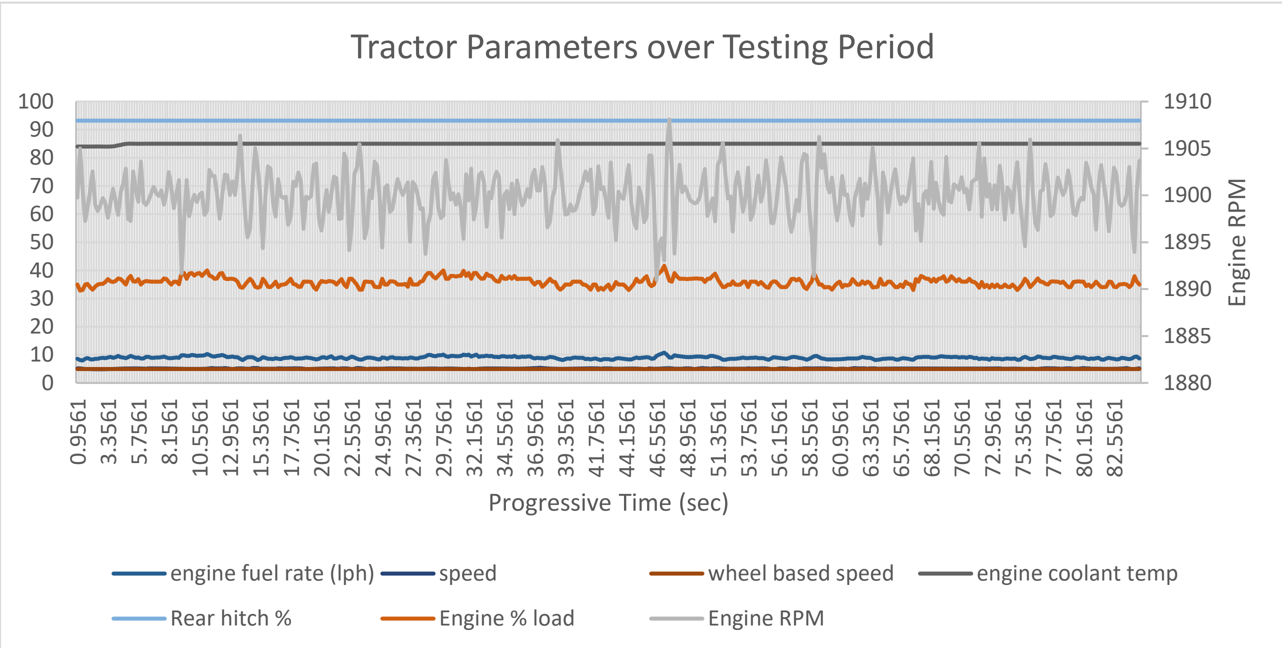
3kph – 2



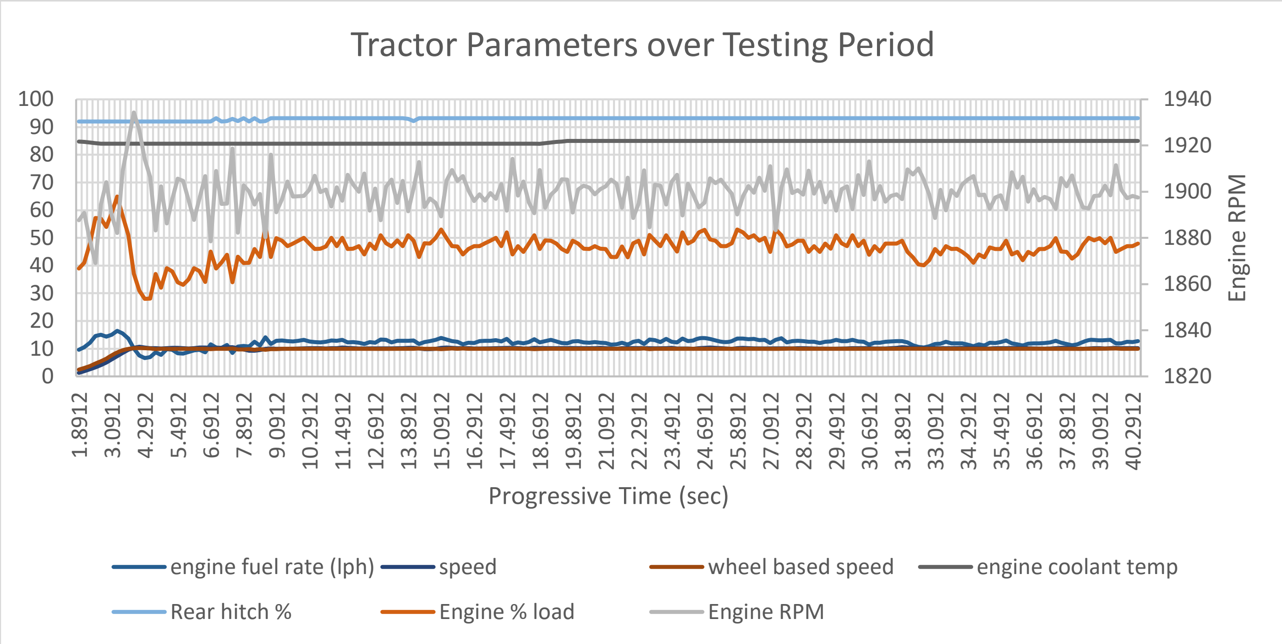
5kph


Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1915
1910
1905
1900
1895
1890
1885
1880
1875
Engine RPM
1.2914
3.8914
6.4914
9.0914
11.6914
14.2914
16.8914
19.4914
22.0914
24.6914
27.2914
29.8914
32.4914
35.0914
37.6914
40.2914
42.8914
45.4914
48.0914
50.6914
53.2914
55.8914
58.4914
61.0914
63.6914
66.2914
68.8914
71.4914
74.0914
76.6914
79.2914
81.8914
84.4914
87.0914
89.6914
92.2914
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

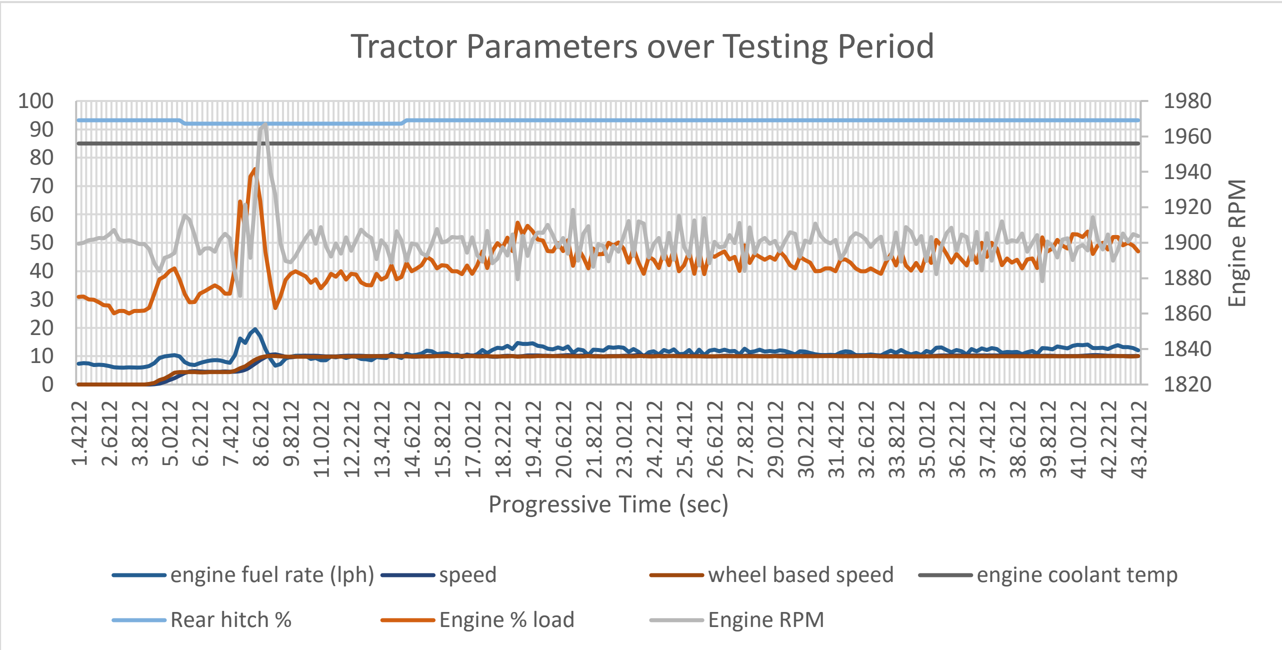
5kph – 2

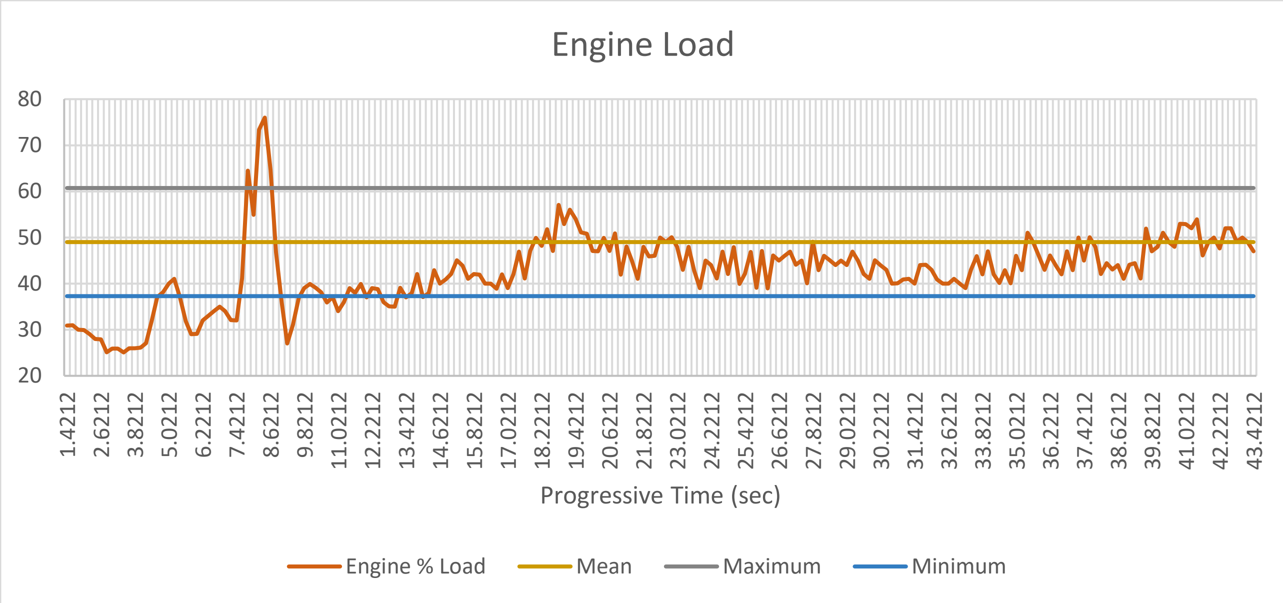

Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1910
1905
1900
1895
1890
1885
1880
Engine RPM
0.9561
3.3561
5.7561
8.1561
10.5561
12.9561
15.3561
17.7561
20.1561
22.5561
24.9561
27.3561
29.7561
32.1561
34.5561
36.9561
39.3561
41.7561
44.1561
46.5561
48.9561
51.3561
53.7561
56.1561
58.5561
60.9561
63.3561
65.7561
68.1561
70.5561
72.9561
75.3561
77.7561
80.1561
82.5561
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

10kph

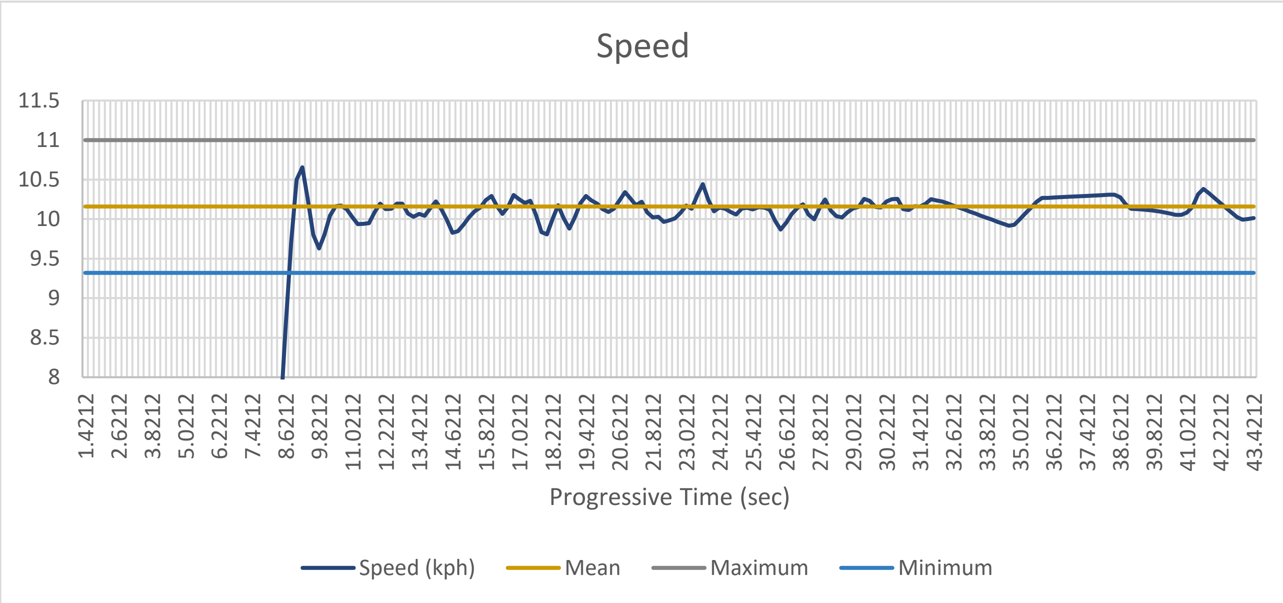


10kph – 2

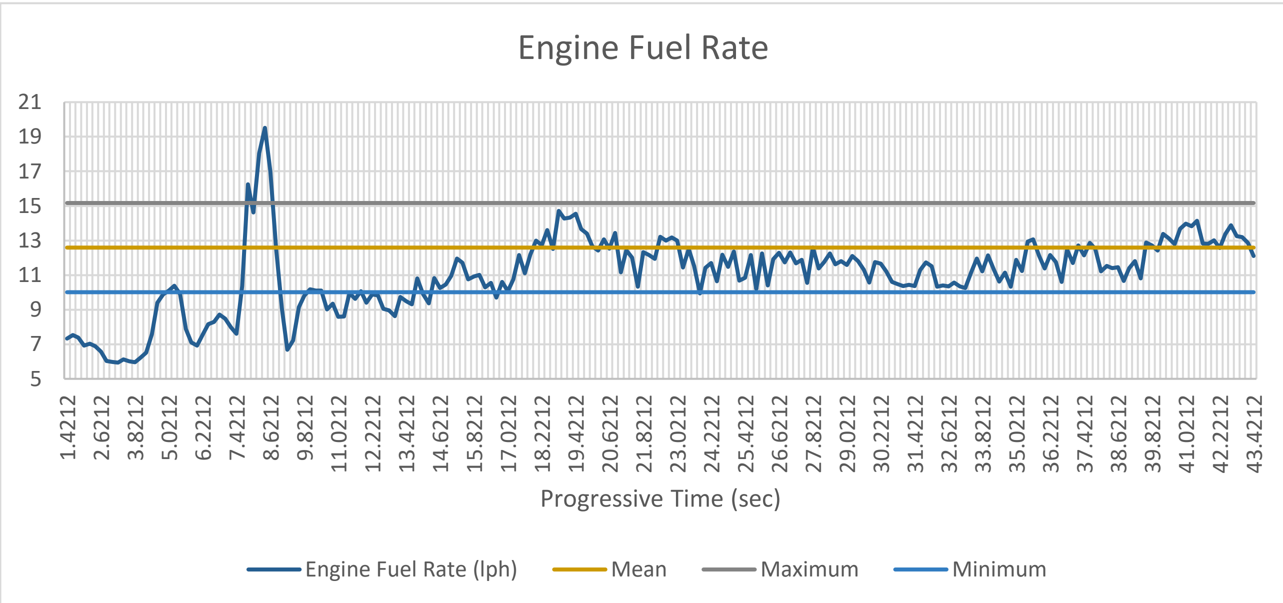




Engine Load
80
70
60
50
40
30
20
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum



Speed
11.5
11
10.5
10
9.5
9
8.5
8
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum



Engine Fuel Rate
21
19
17
15
13
11
9
7
5
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
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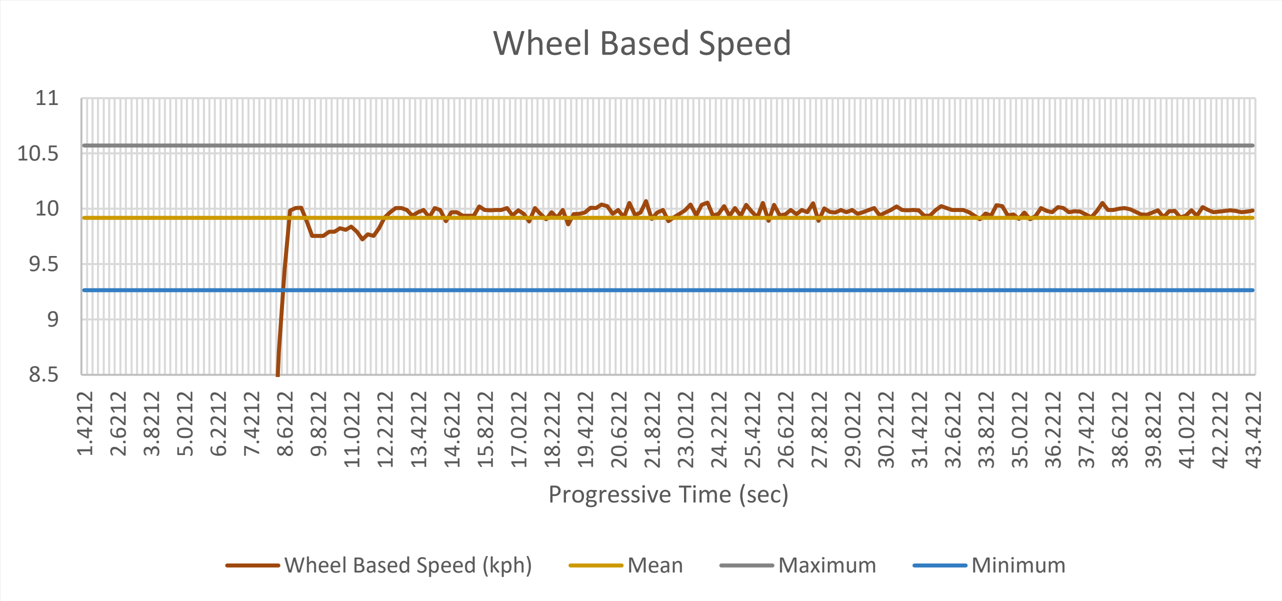
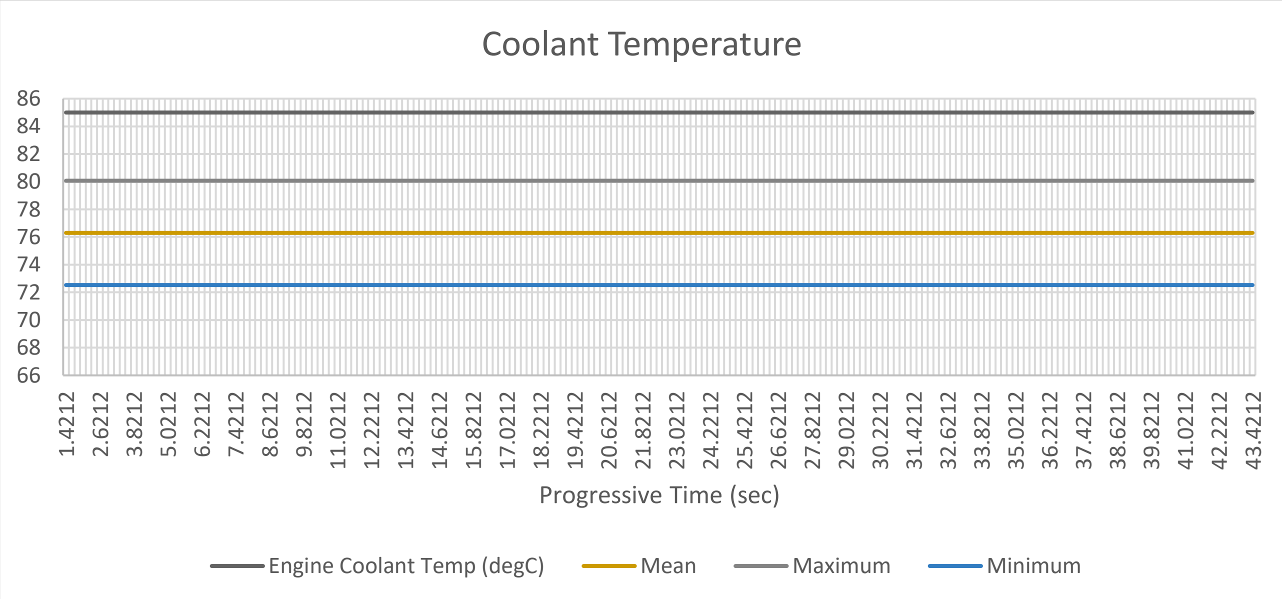
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
11
10.5
10
9.5
9
8.5
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
86
84
82
80
78
76
74
72
70
68
66
1.4212
2.6212
3.8212
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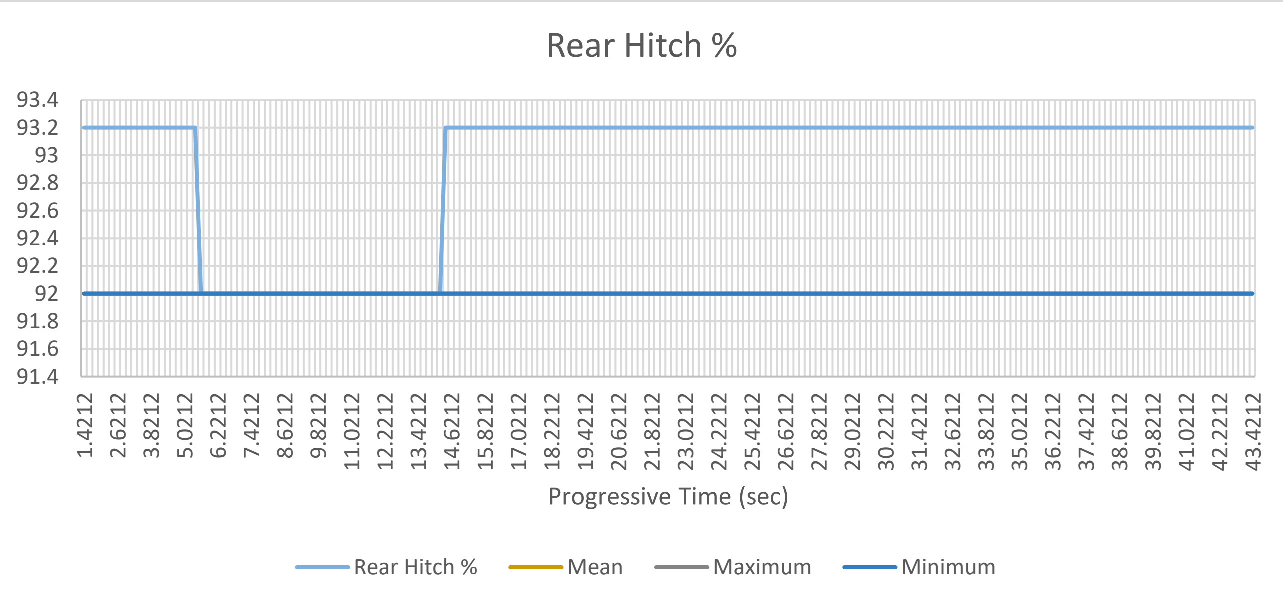
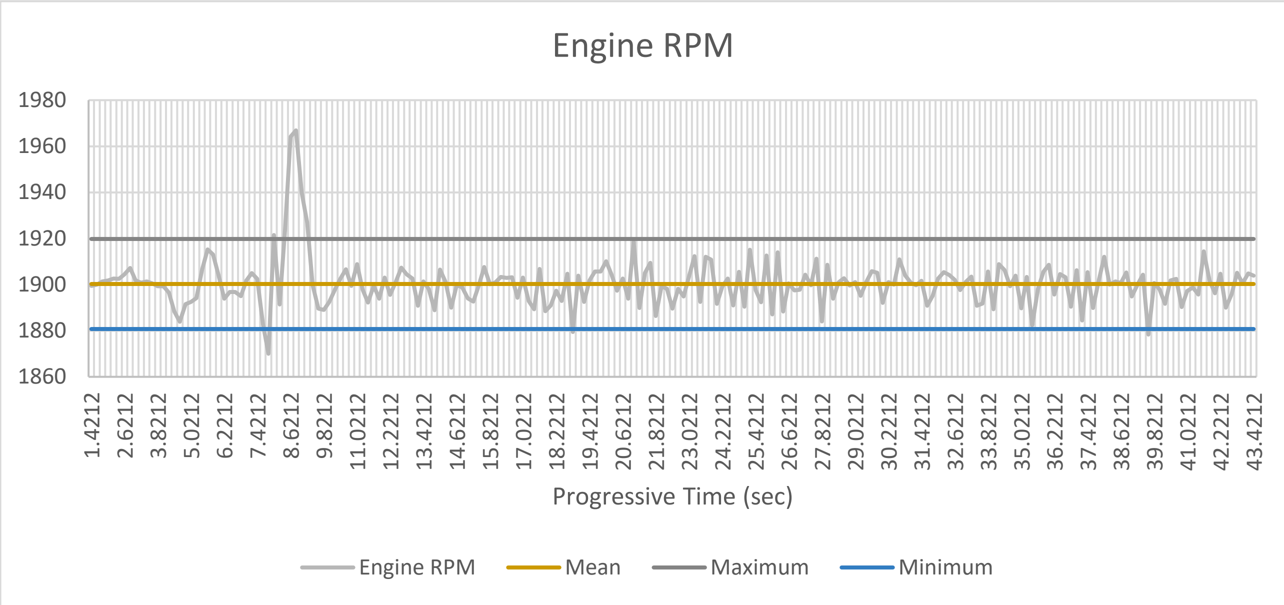
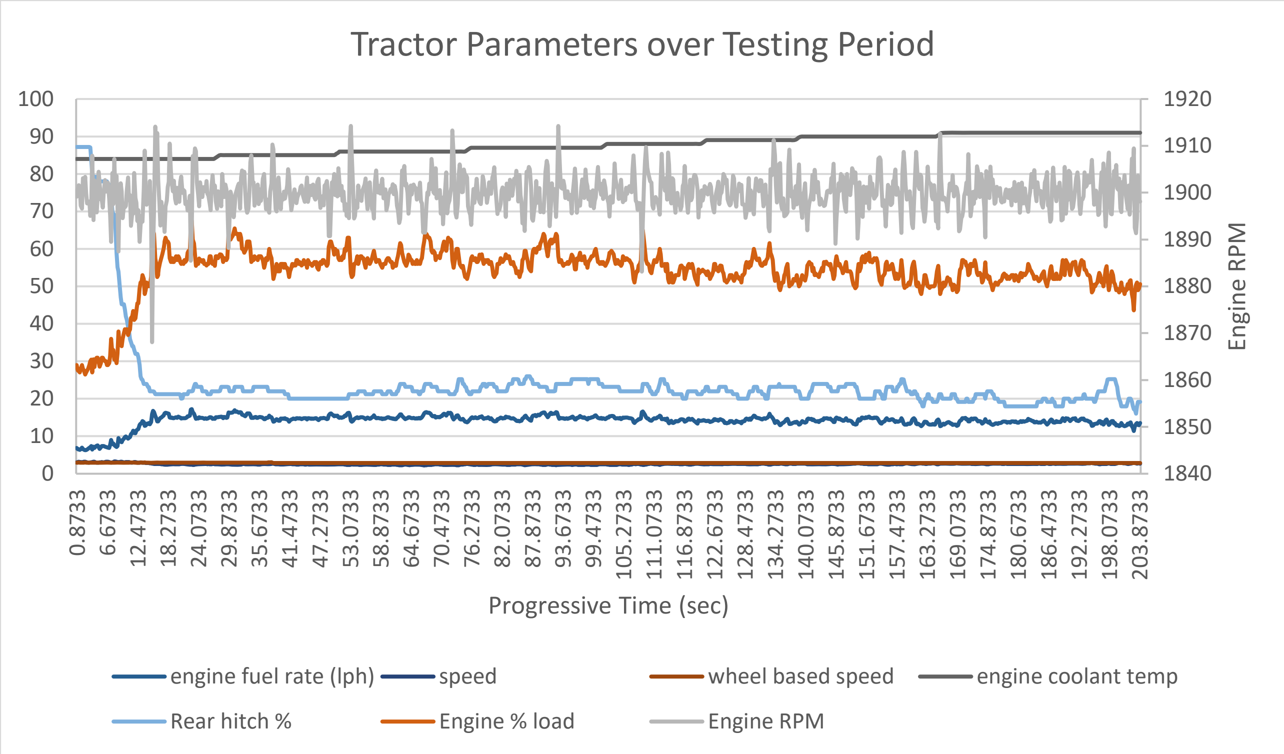
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum


Rear Hitch %
93.4
93.2
93
92.8
92.6
92.4
92.2
92
91.8
91.6
91.4
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

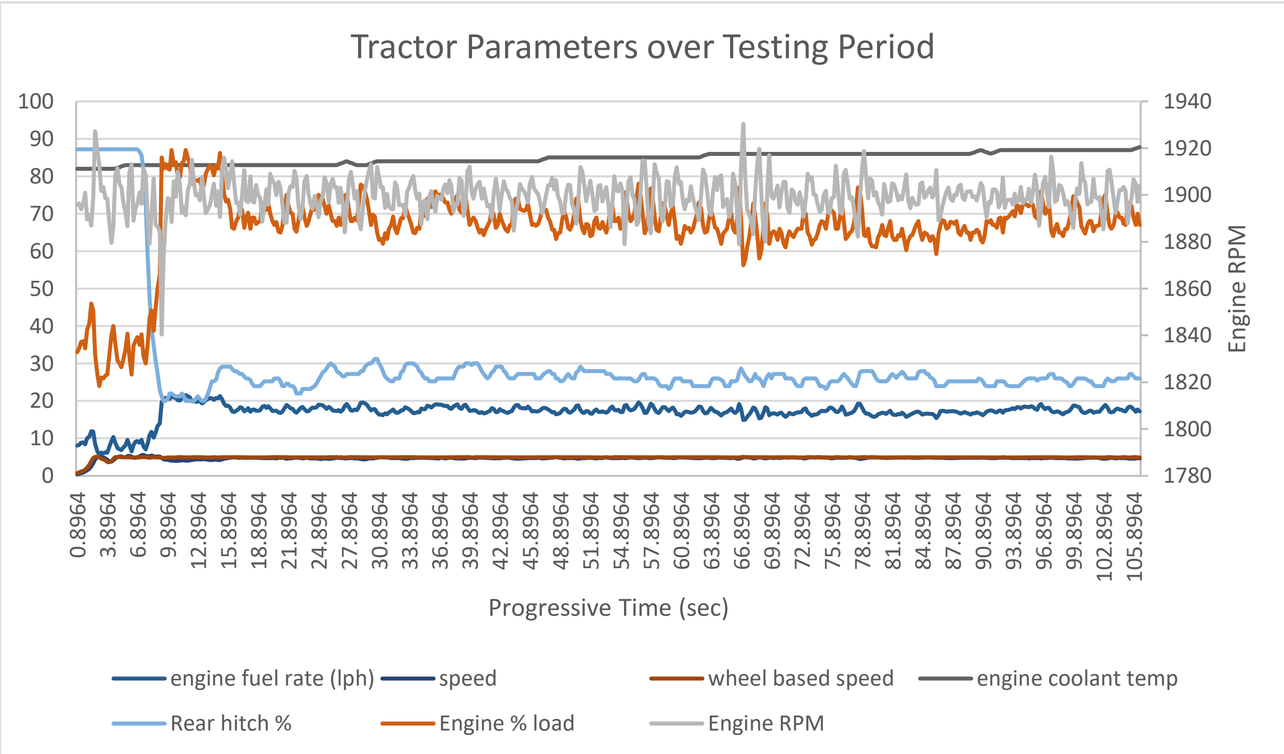

Engine RPM
1980
1960
1940
1920
1900
1880
1860
1.4212
2.6212
3.8212
5.0212
6.2212
7.4212
8.6212
9.8212
11.0212
12.2212
13.4212
14.6212
15.8212
17.0212
18.2212
19.4212
20.6212
21.8212
23.0212
24.2212
25.4212
26.6212
27.8212
29.0212
30.2212
31.4212
32.6212
33.8212
35.0212
36.2212
37.4212
38.6212
39.8212
41.0212
42.2212
43.4212
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

Appendix F – 3PL Deep Ripper – Base run data

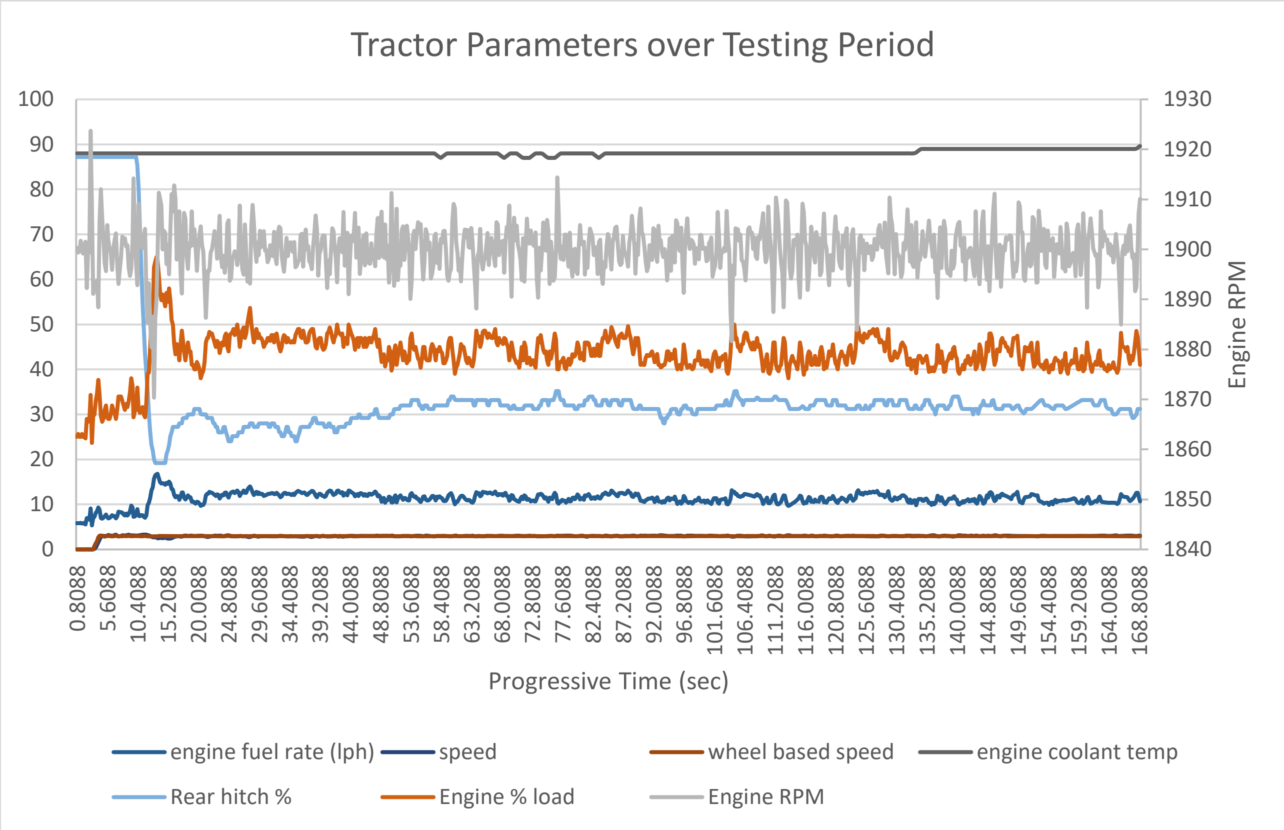
350mm – 3kph



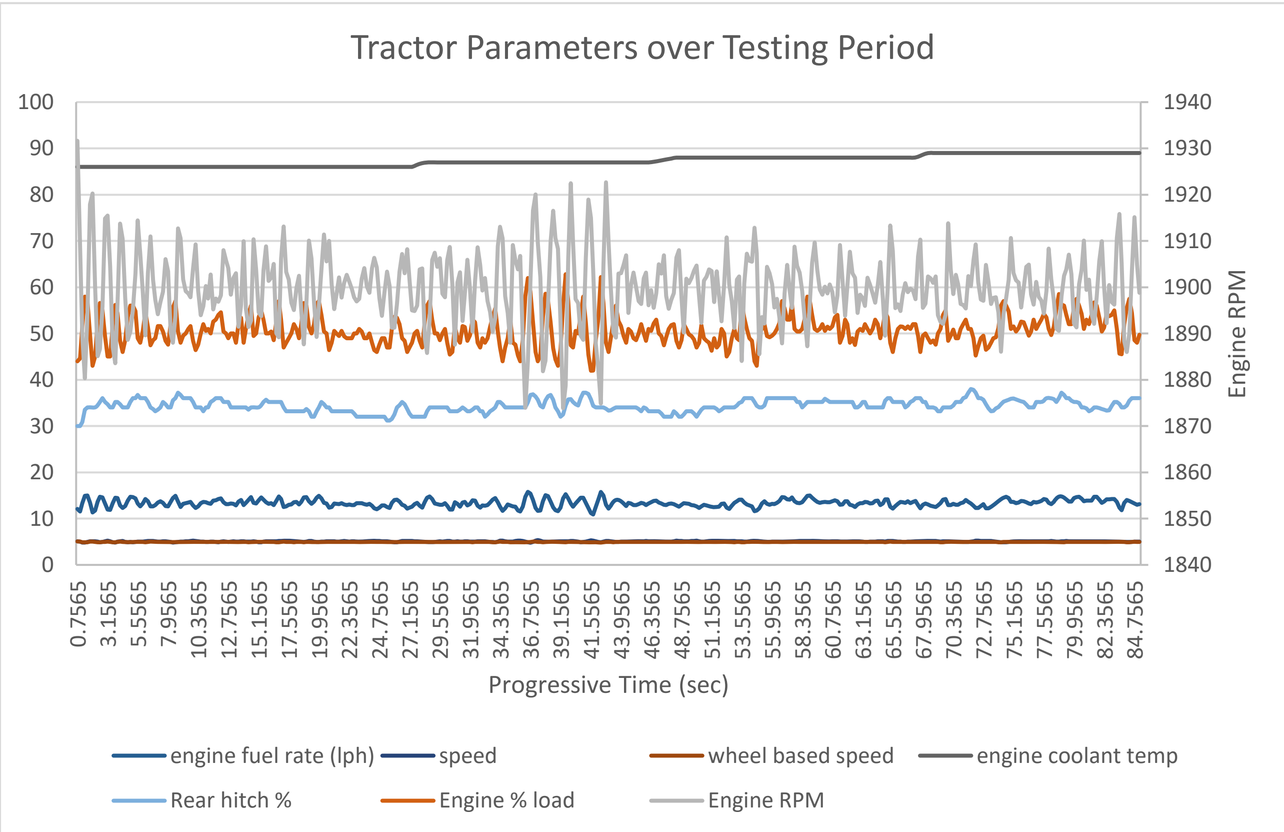
350mm – 5kph



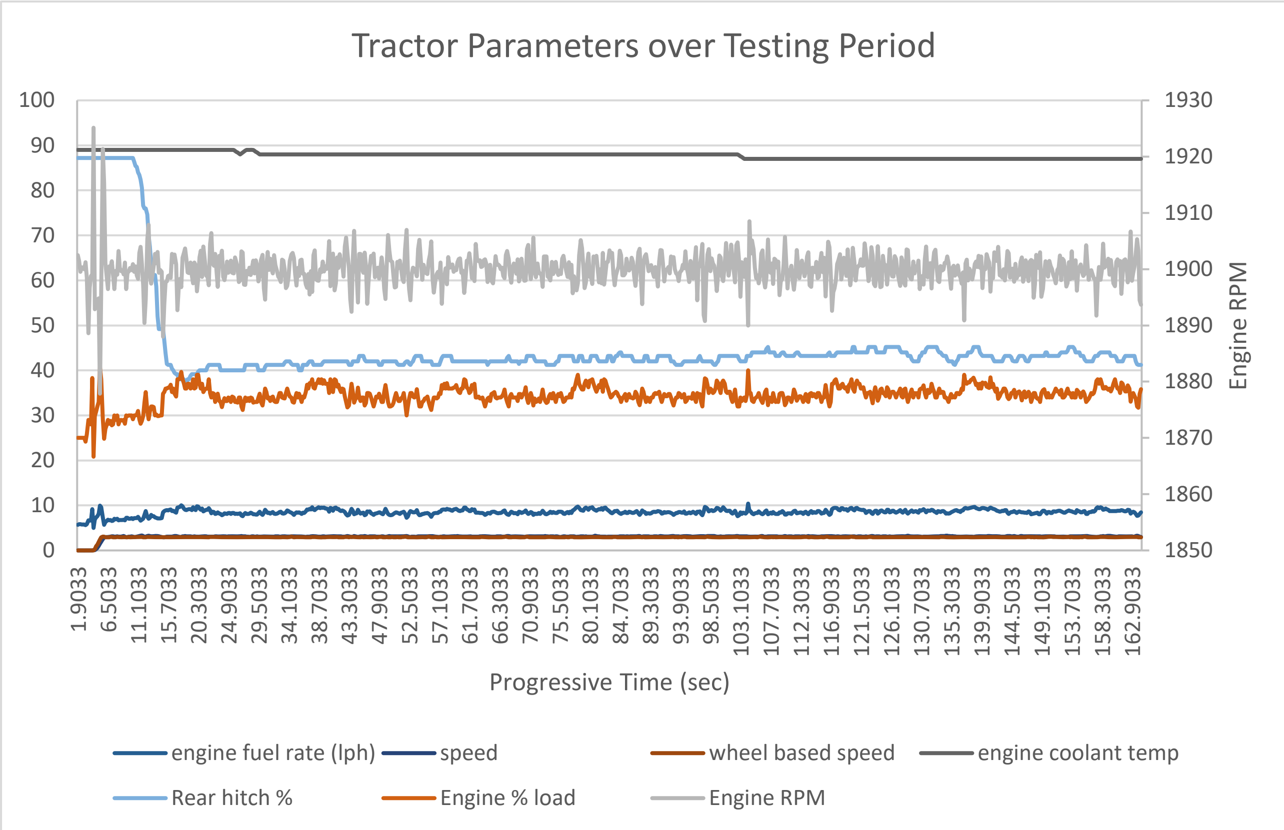
300mm – 3kph



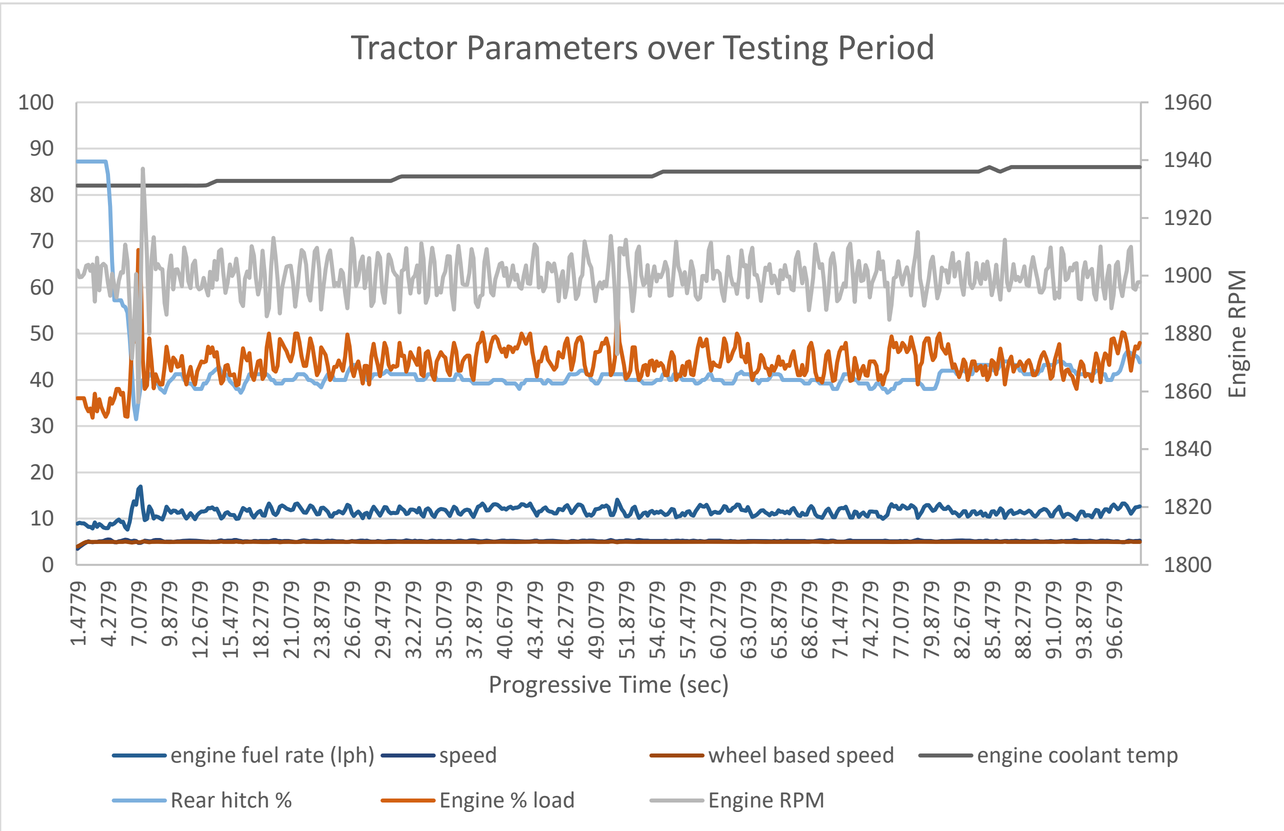
300mm – 5kph



200mm – 3kph

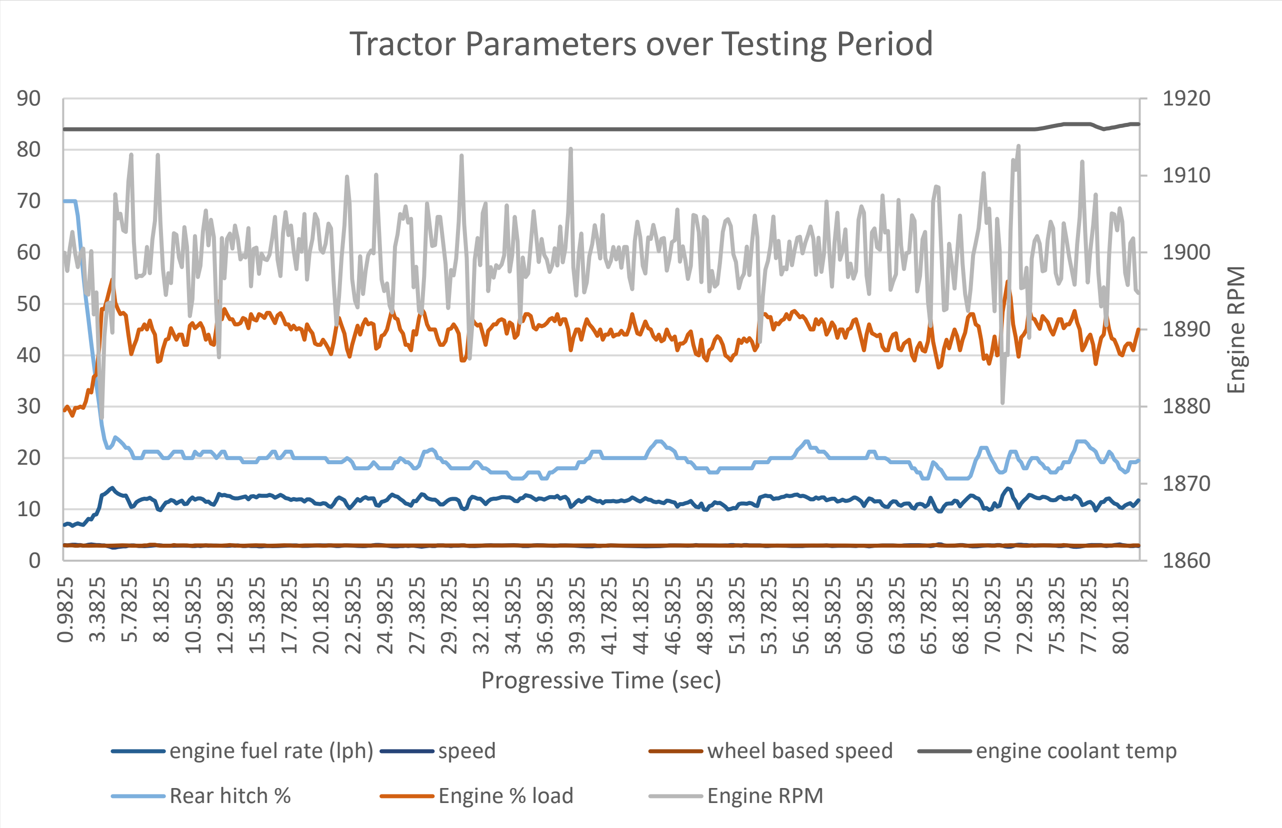


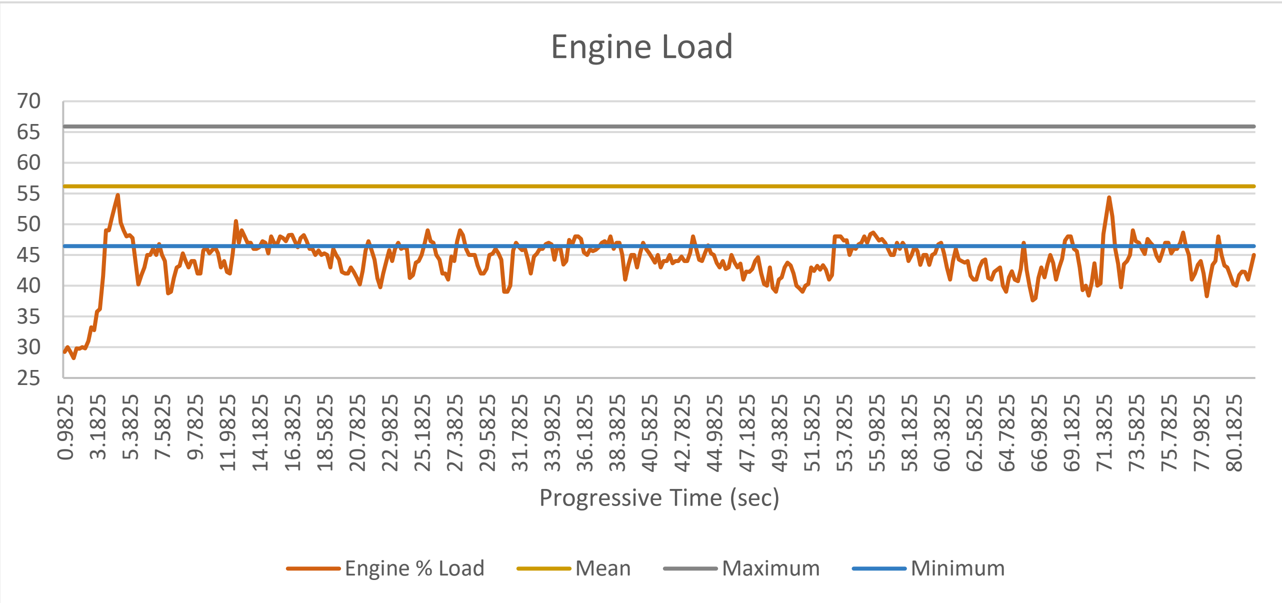
200mm – 5kph

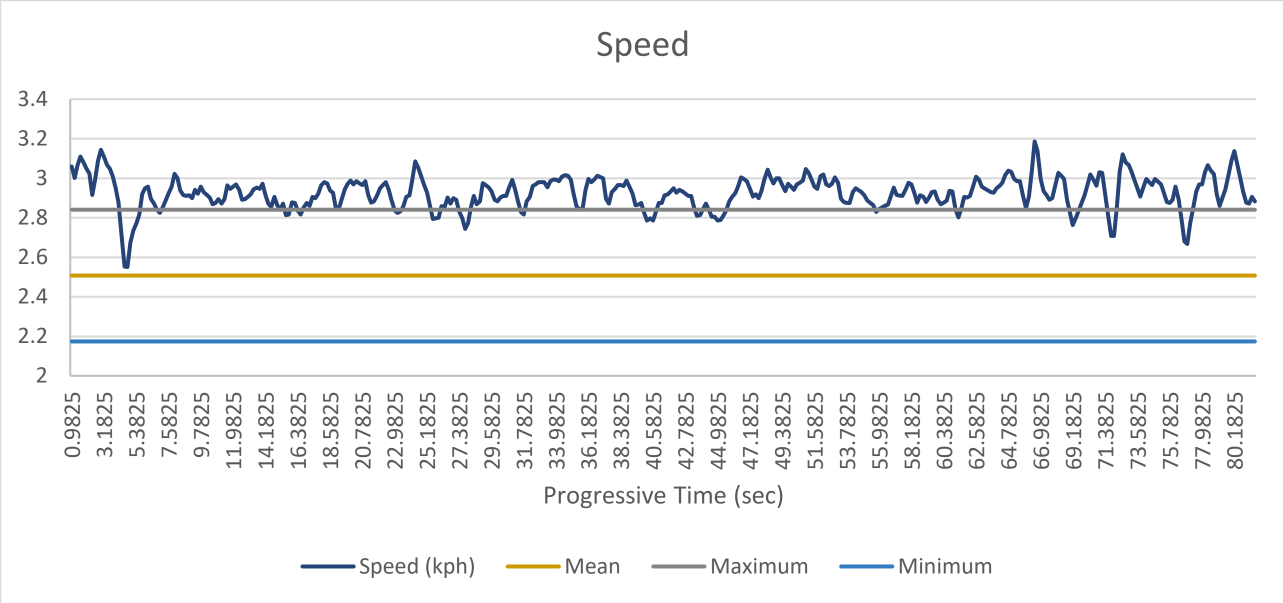


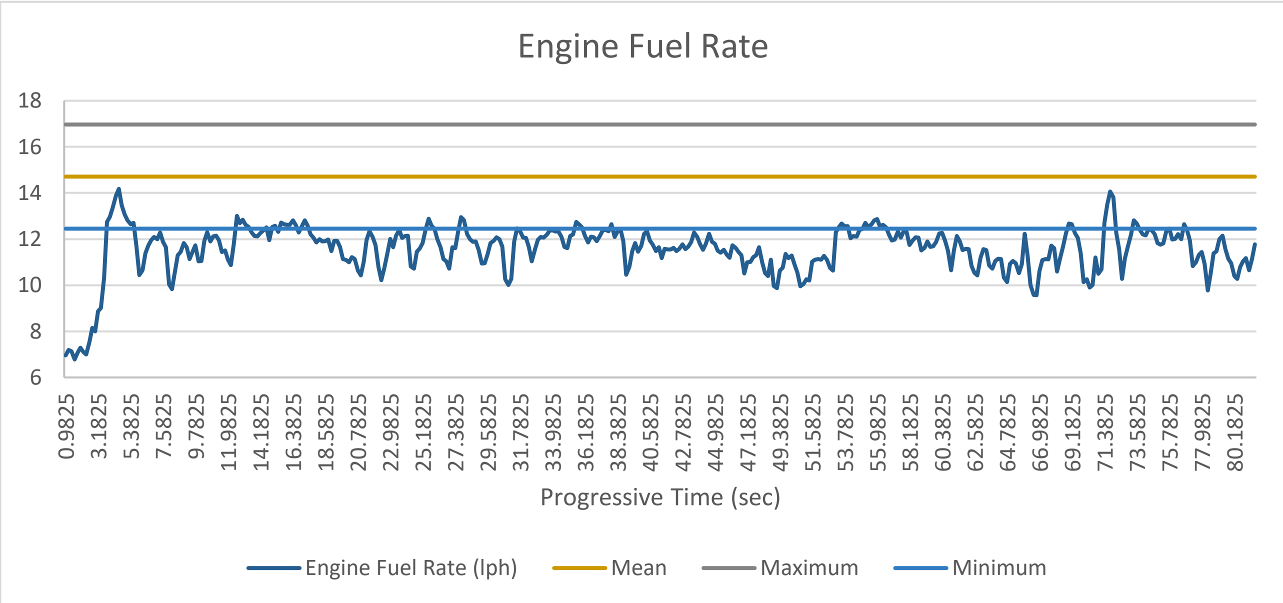
Appendix G – 3PL Deep Ripper – Ripper shank shear pin breaking data

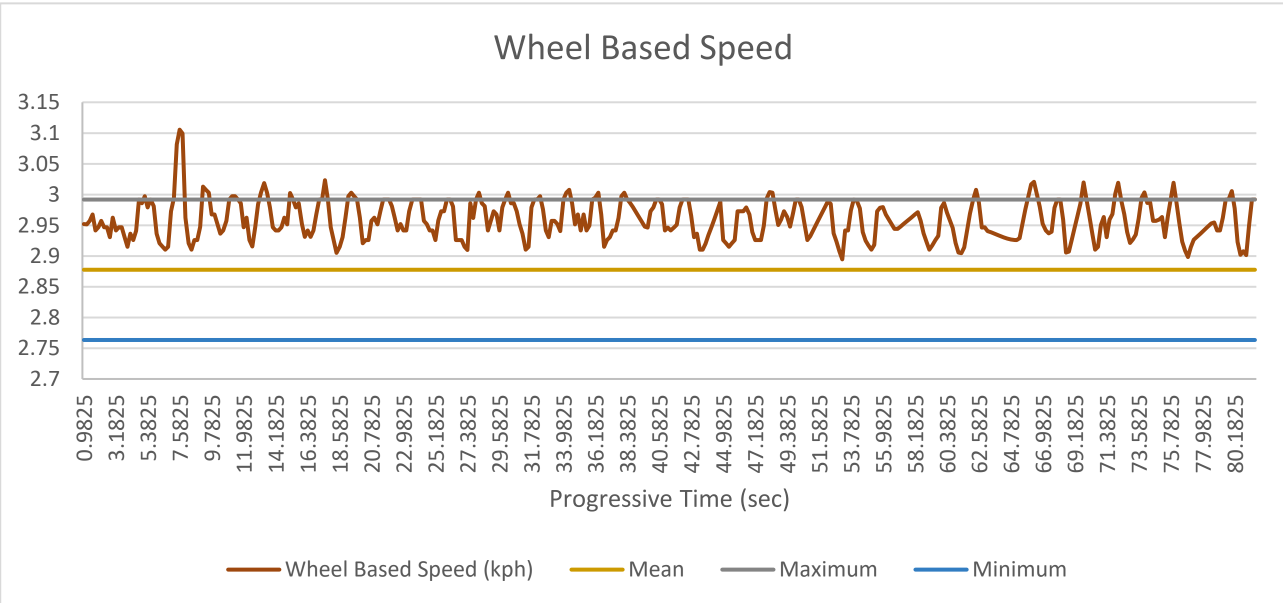
350mm – 3kph

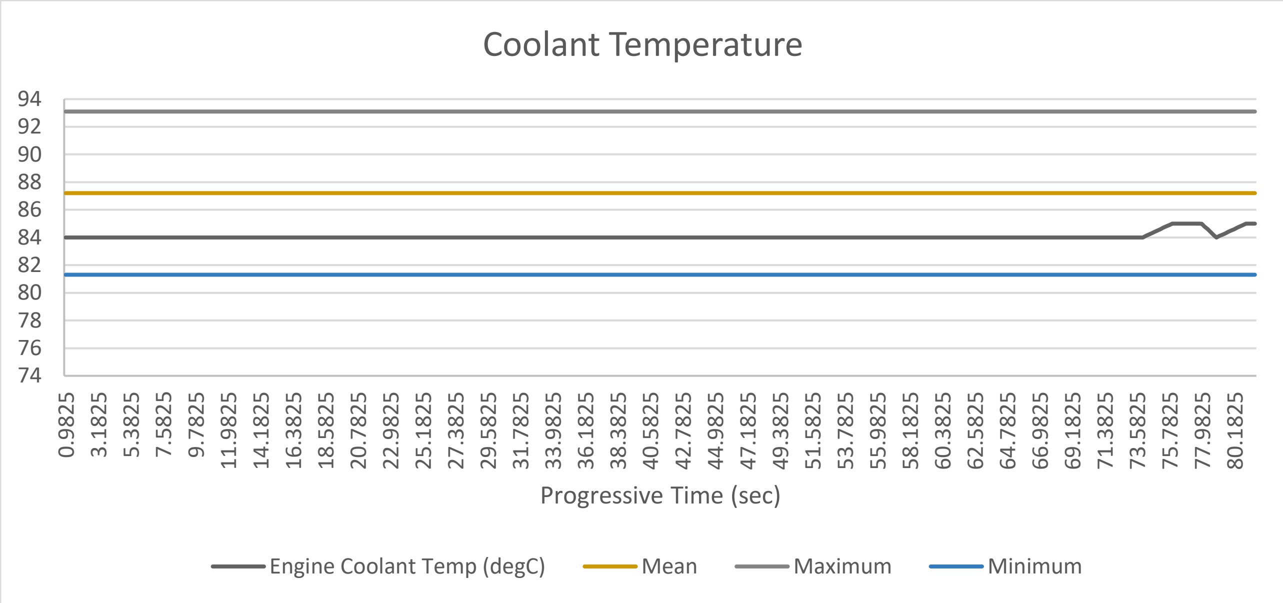


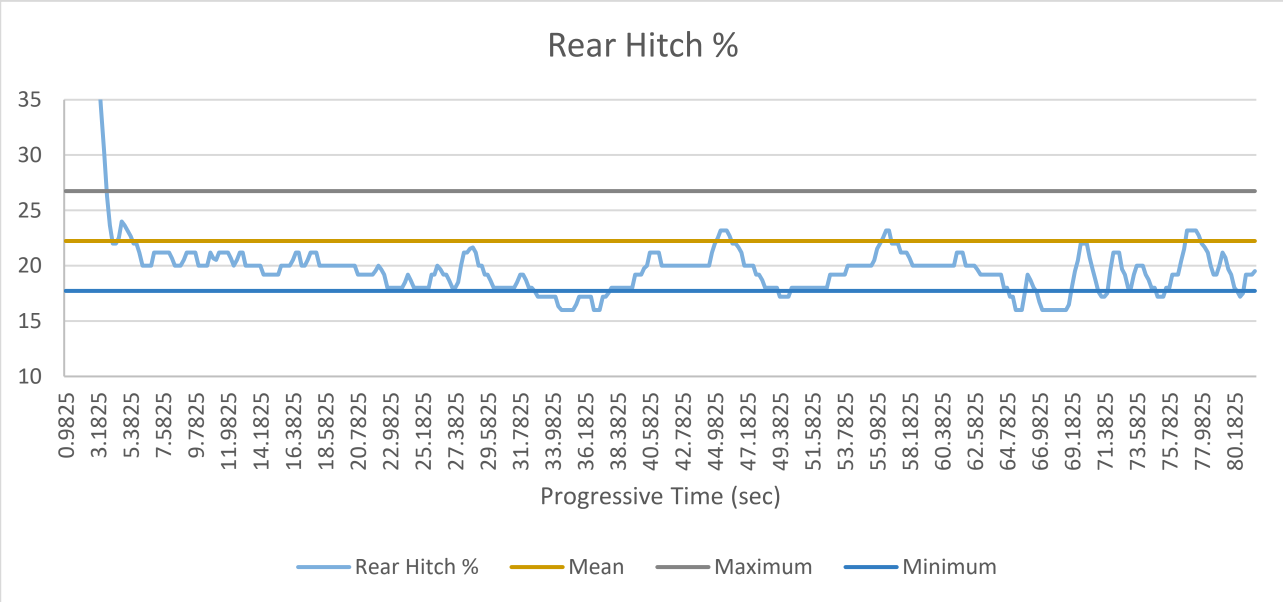


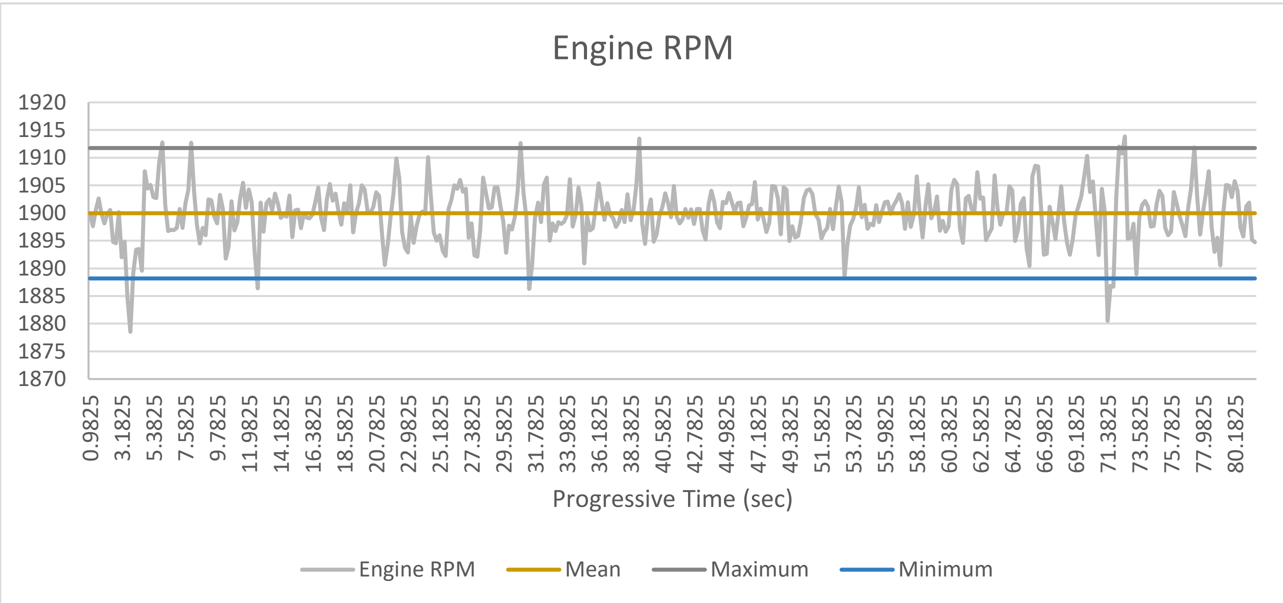

Speed
3.4
3.2
3
2.8
2.6
2.4
2.2
2
0.9825
3.1825
5.3825
7.5825
9.7825
11.9825
14.1825
16.3825
18.5825
20.7825
22.9825
25.1825
27.3825
29.5825
31.7825
33.9825
36.1825
38.3825
40.5825
42.7825
44.9825
47.1825
49.3825
51.5825
53.7825
55.9825
58.1825
60.3825
62.5825
64.7825
66.9825
69.1825
71.3825
73.5825
75.7825
77.9825
80.1825
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
18
16
14
12
10
8
6
0.9825
3.1825
5.3825
7.5825
9.7825
11.9825
14.1825
16.3825
18.5825
20.7825
22.9825
25.1825
27.3825
29.5825
31.7825
33.9825
36.1825
38.3825
40.5825
42.7825
44.9825
47.1825
49.3825
51.5825
53.7825
55.9825
58.1825
60.3825
62.5825
64.7825
66.9825
69.1825
71.3825
73.5825
75.7825
77.9825
80.1825
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

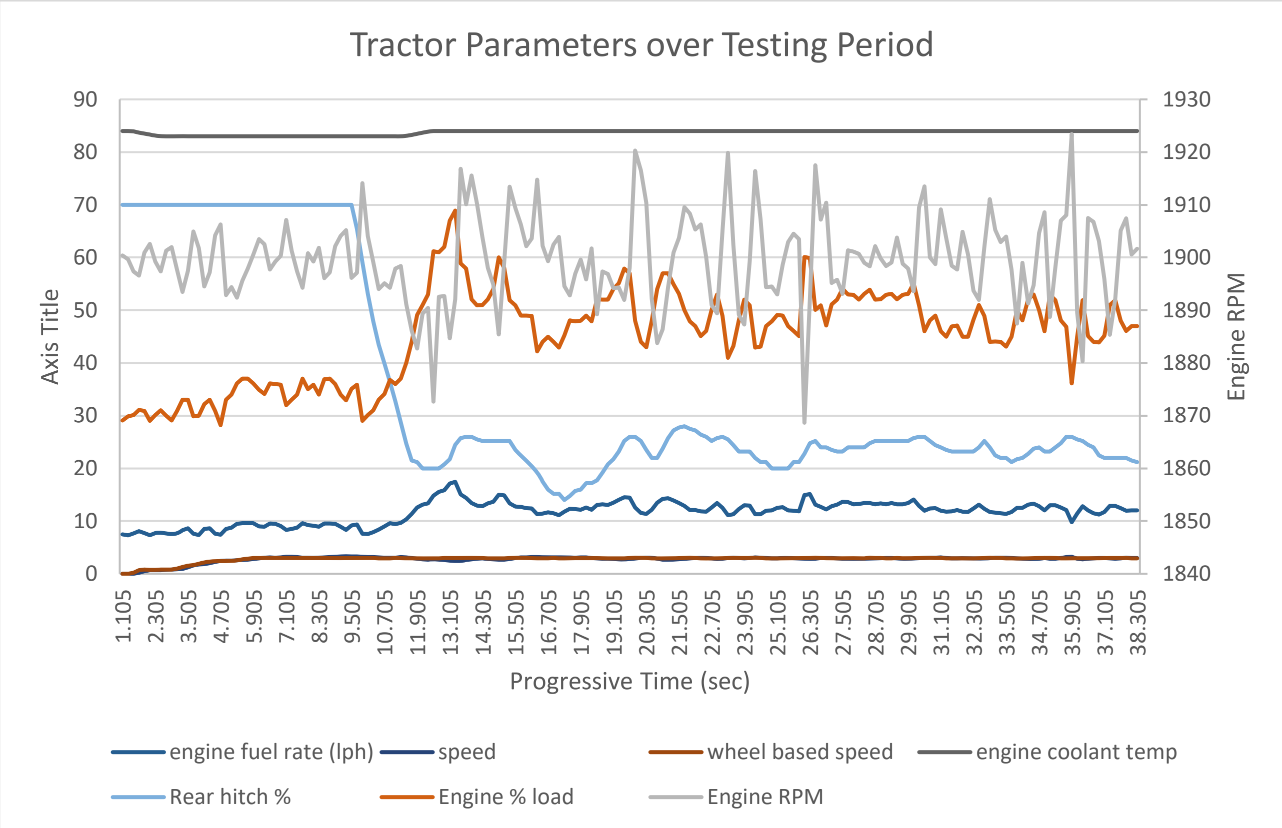

Wheel Based Speed
3.15
3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
0.9825
3.1825
5.3825
7.5825
9.7825
11.9825
14.1825
16.3825
18.5825
20.7825
22.9825
25.1825
27.3825
29.5825
31.7825
33.9825
36.1825
38.3825
40.5825
42.7825
44.9825
47.1825
49.3825
51.5825
53.7825
55.9825
58.1825
60.3825
62.5825
64.7825
66.9825
69.1825
71.3825
73.5825
75.7825
77.9825
80.1825
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
94
92
90
88
86
84
82
80
78
76
74
0.9825 3.1825 5.3825 7.5825 9.7825 11.9825 14.1825 16.3825 18.5825 20.7825 22.9825 25.1825 27.3825 29.5825 31.7825 33.9825 36.1825 38.3825 40.5825 42.7825 44.9825 47.1825 49.3825 51.5825 53.7825 55.9825 58.1825 60.3825 62.5825 64.7825 66.9825 69.1825 71.3825 73.5825 75.7825 77.9825 80.1825
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

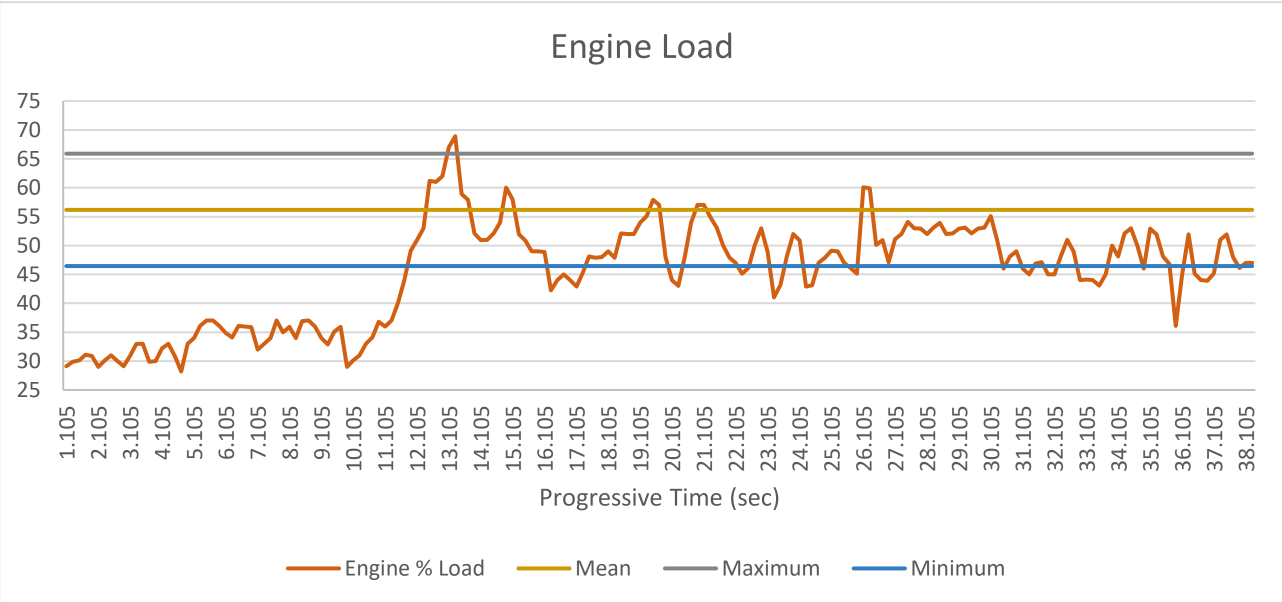

Rear Hitch %
35
30
25
20
15
10
0.9825 3.1825 5.3825 7.5825 9.7825 11.9825 14.1825 16.3825 18.5825 20.7825 22.9825 25.1825 27.3825 29.5825 31.7825 33.9825 36.1825 38.3825 40.5825 42.7825 44.9825 47.1825 49.3825 51.5825 53.7825 55.9825 58.1825 60.3825 62.5825 64.7825 66.9825 69.1825 71.3825 73.5825 75.7825 77.9825 80.1825
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875
1870
0.9825 3.1825 5.3825 7.5825 9.7825 11.9825 14.1825 16.3825 18.5825 20.7825 22.9825 25.1825 27.3825 29.5825 31.7825 33.9825 36.1825 38.3825 40.5825 42.7825 44.9825 47.1825 49.3825 51.5825 53.7825 55.9825 58.1825 60.3825 62.5825 64.7825 66.9825 69.1825 71.3825 73.5825 75.7825 77.9825 80.1825
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

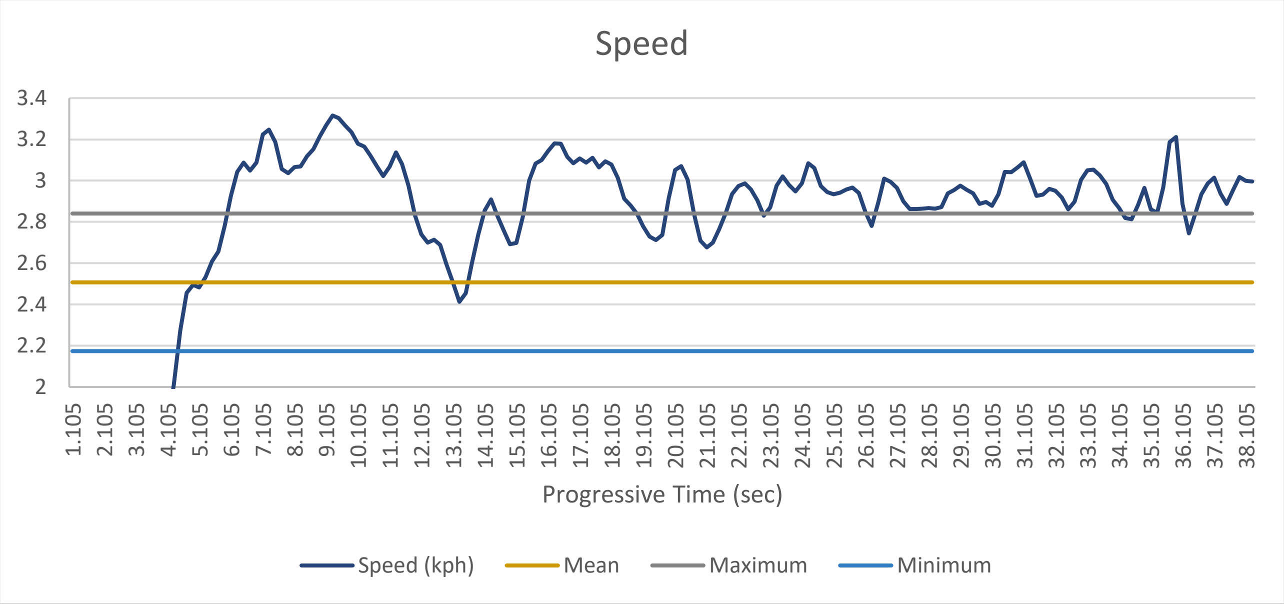
350mm – 3kph – 2

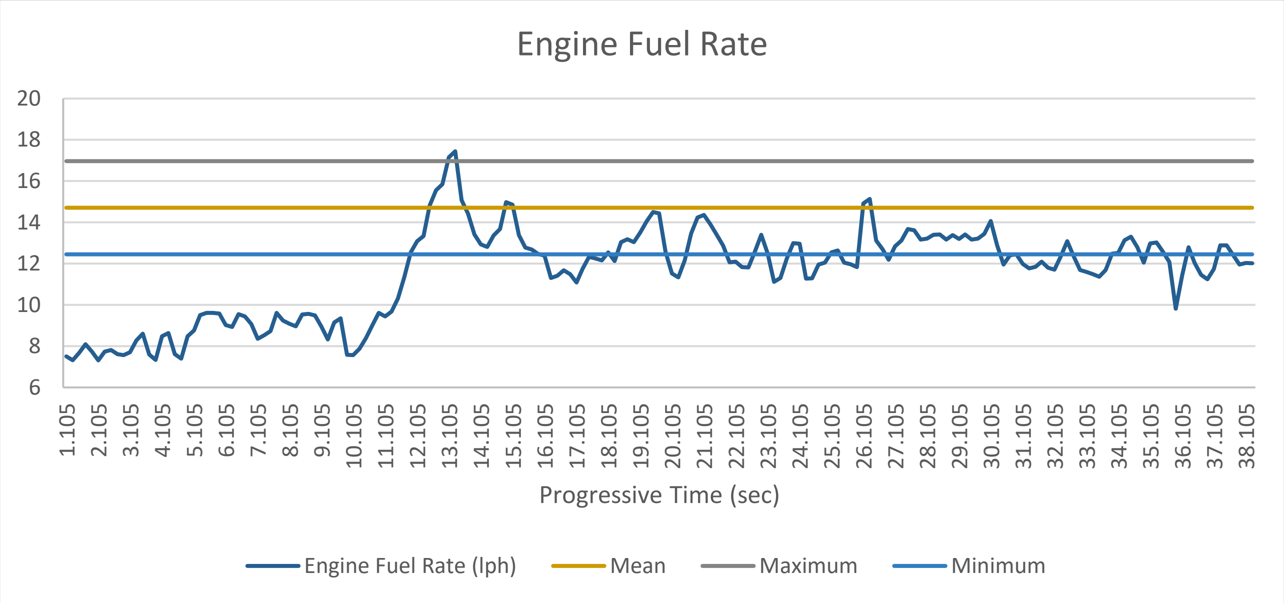


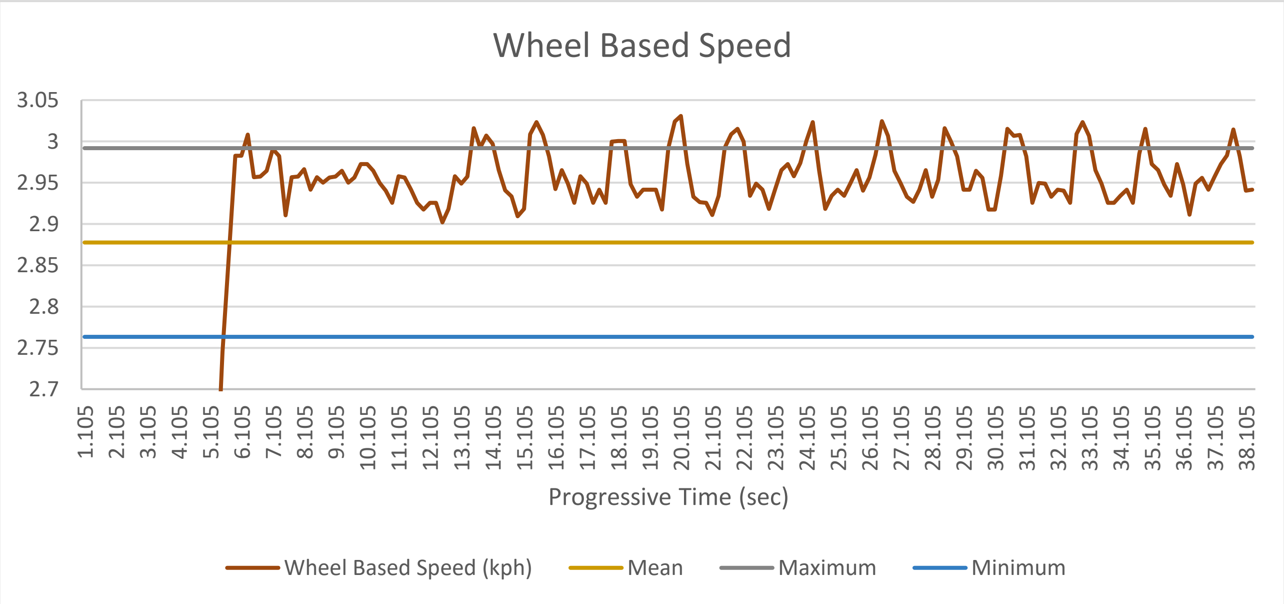
Tractor Parameters over Testing Period
Axis Title
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

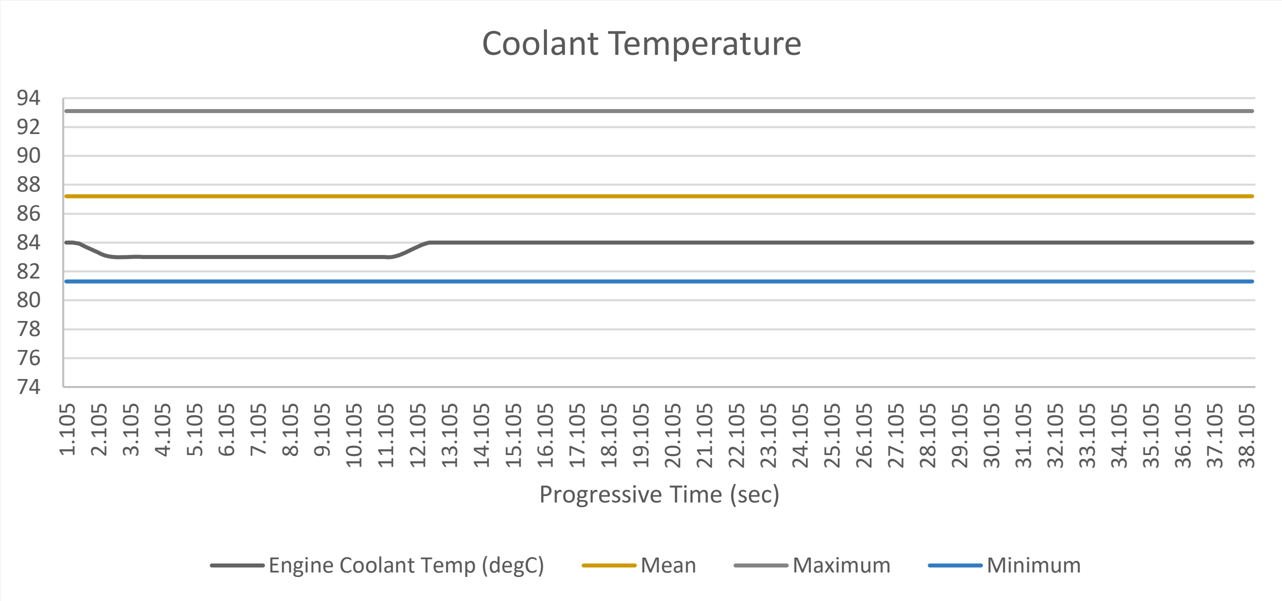


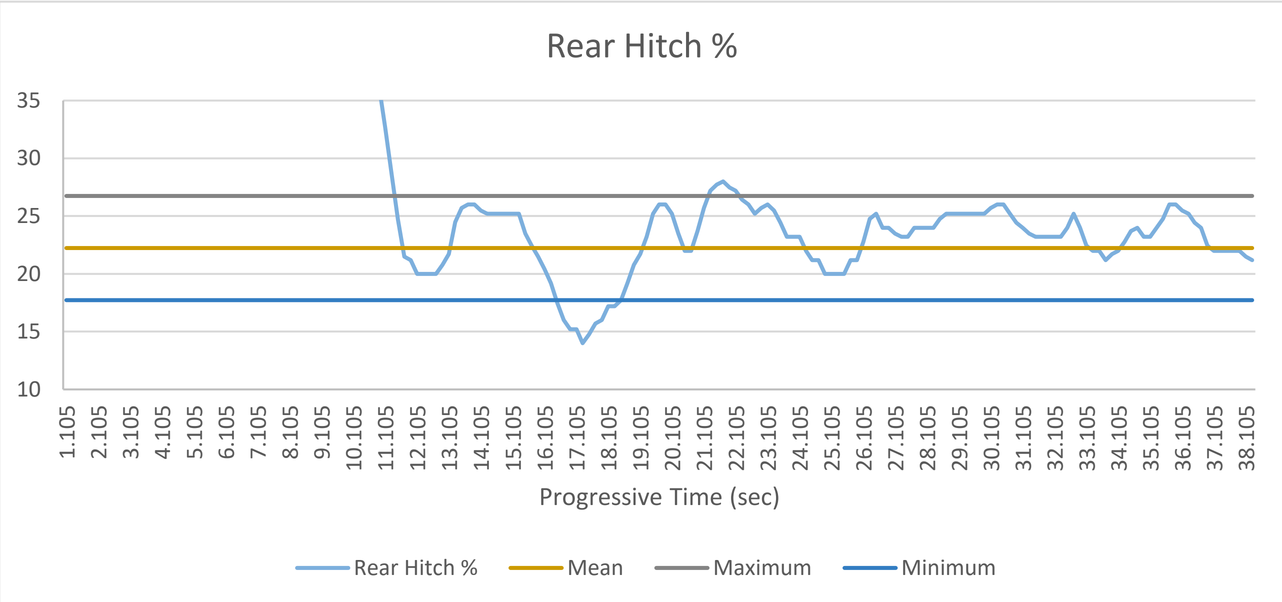
Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

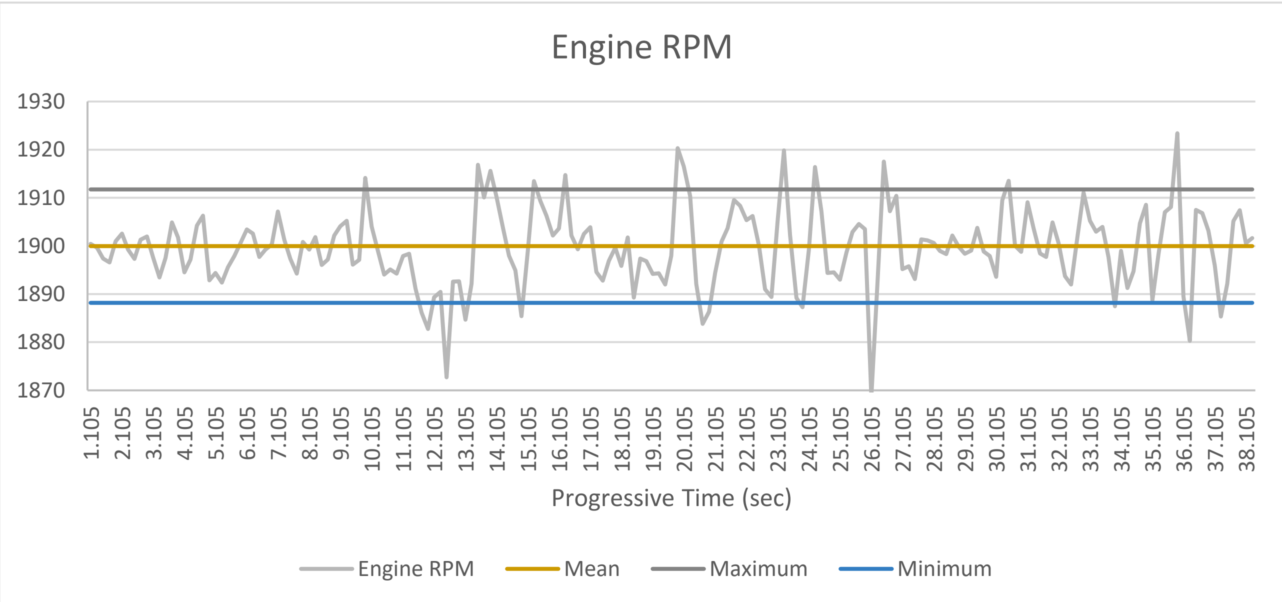

Speed
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.105
2.105
3.105
4.105
5.105
6.105
7.105
8.105
9.105
10.105
11.105
12.105
13.105
14.105
15.105
16.105
17.105
18.105
19.105
20.105
21.105
22.105
23.105
24.105
25.105
26.105
27.105
28.105
29.105
30.105
31.105
32.105
33.105
34.105
35.105
36.105
37.105
38.105
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
20
18
16
14
12
10
8
6
1.105
2.105
3.105
4.105
5.105
6.105
7.105
8.105
9.105
10.105
11.105
12.105
13.105
14.105
15.105
16.105
17.105
18.105
19.105
20.105
21.105
22.105
23.105
24.105
25.105
26.105
27.105
28.105
29.105
30.105
31.105
32.105
33.105
34.105
35.105
36.105
37.105
38.105
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

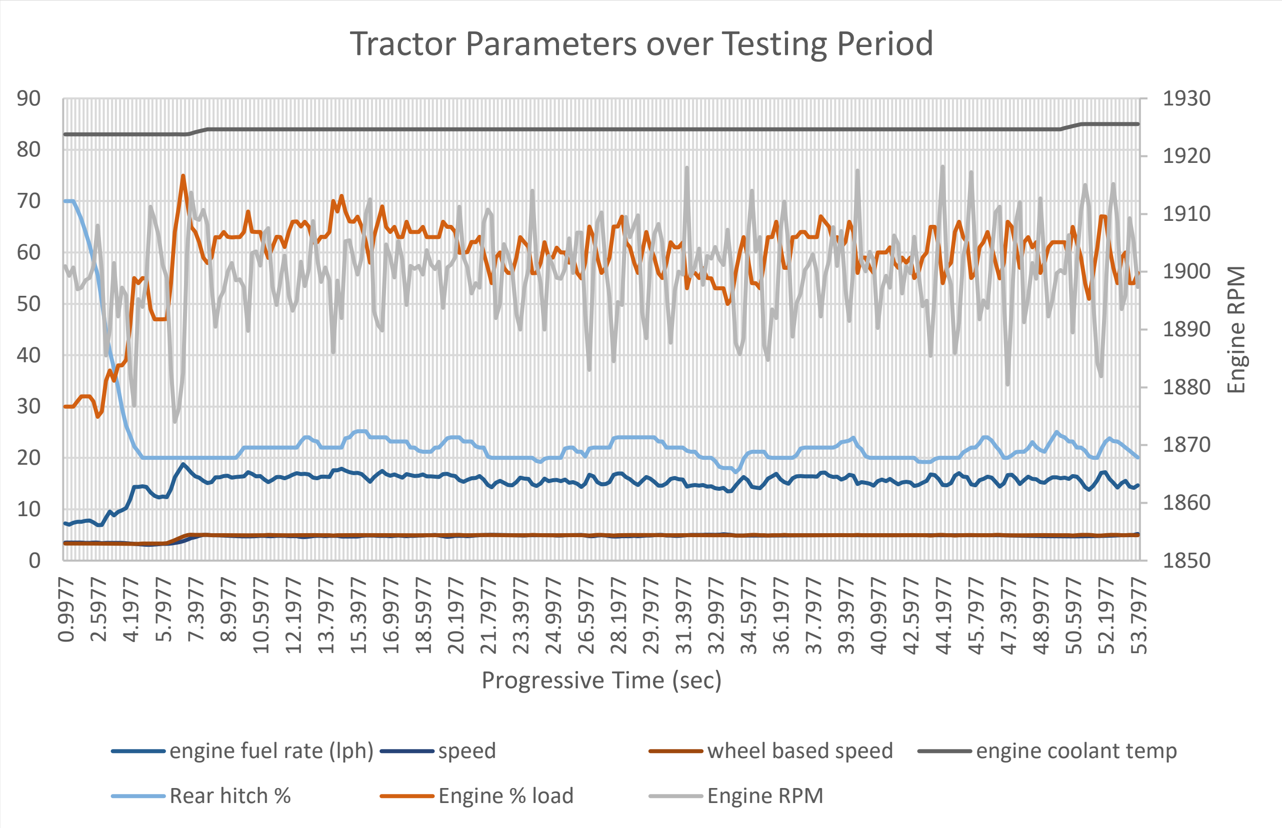

Wheel Based Speed
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
1.105
2.105
3.105
4.105
5.105
6.105
7.105
8.105
9.105
10.105
11.105
12.105
13.105
14.105
15.105
16.105
17.105
18.105
19.105
20.105
21.105
22.105
23.105
24.105
25.105
26.105
27.105
28.105
29.105
30.105
31.105
32.105
33.105
34.105
35.105
36.105
37.105
38.105
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

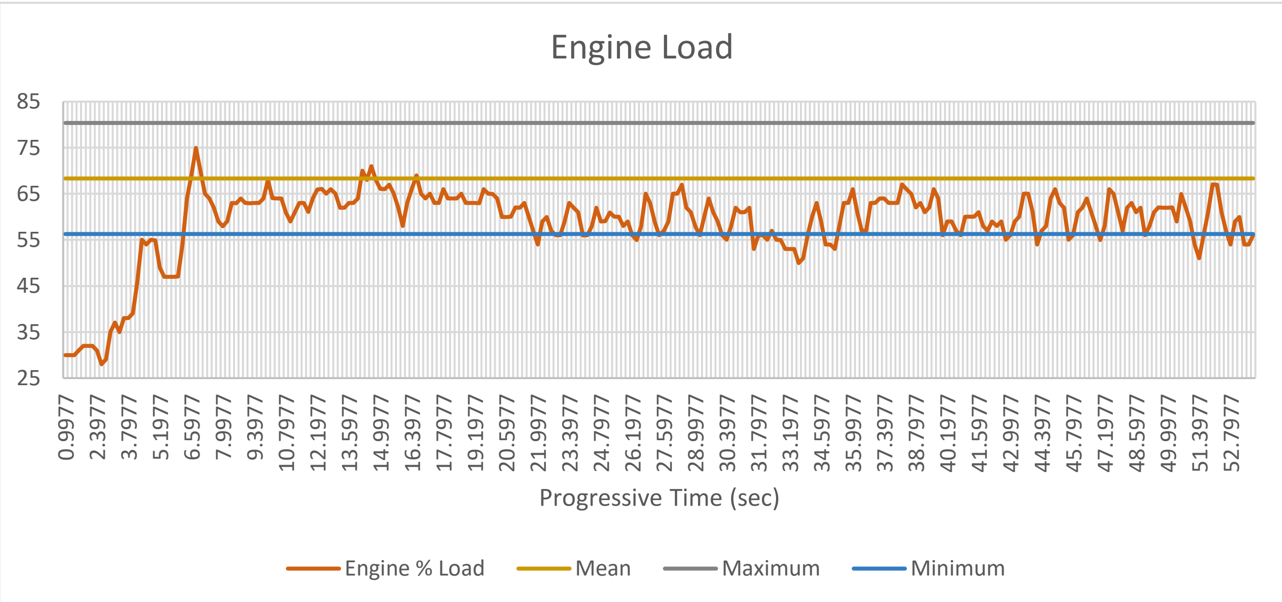

Coolant Temperature
94
92
90
88
86
84
82
80
78
76
74
1.105 2.105 3.105 4.105 5.105 6.105 7.105 8.105 9.105 10.105 11.105 12.105 13.105 14.105 15.105 16.105 17.105 18.105 19.105 20.105 21.105 22.105 23.105 24.105 25.105 26.105 27.105 28.105 29.105 30.105 31.105 32.105 33.105 34.105 35.105 36.105 37.105 38.105
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

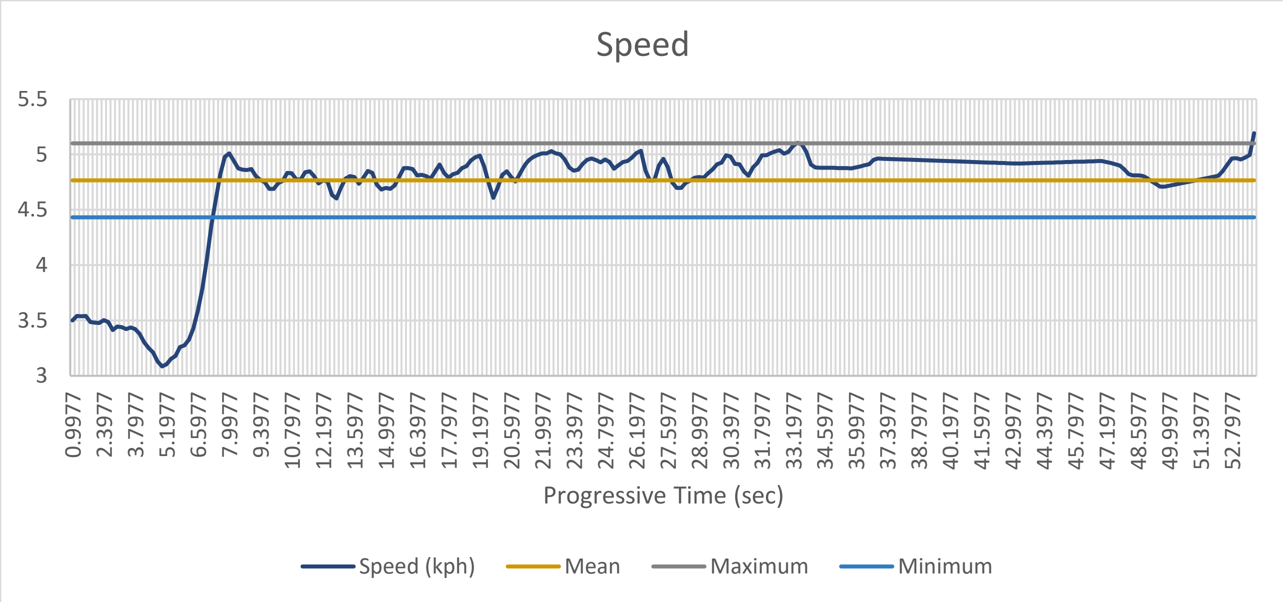

Rear Hitch %
35
30
25
20
15
10
1.105 2.105 3.105 4.105 5.105 6.105 7.105 8.105 9.105 10.105 11.105 12.105 13.105 14.105 15.105 16.105 17.105 18.105 19.105 20.105 21.105 22.105 23.105 24.105 25.105 26.105 27.105 28.105 29.105 30.105 31.105 32.105 33.105 34.105 35.105 36.105 37.105 38.105
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

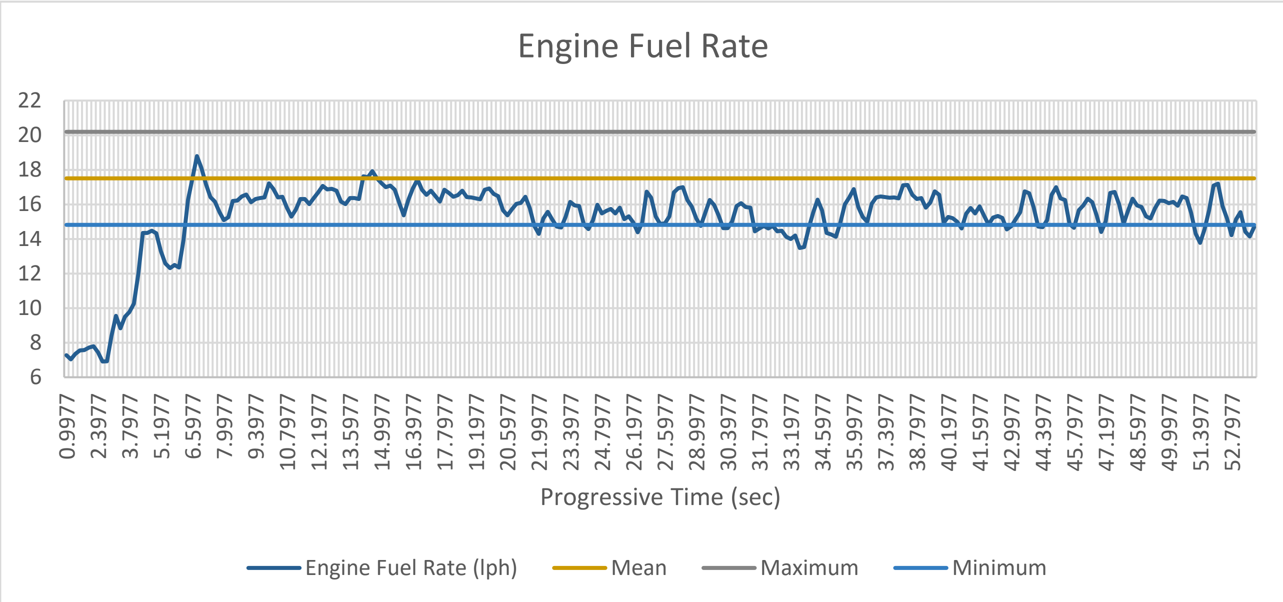

Engine RPM
1930
1920
1910
1900
1890
1880
1870
1.105 2.105 3.105 4.105 5.105 6.105 7.105 8.105 9.105 10.105 11.105 12.105 13.105 14.105 15.105 16.105 17.105 18.105 19.105 20.105 21.105 22.105 23.105 24.105 25.105 26.105 27.105 28.105 29.105 30.105 31.105 32.105 33.105 34.105 35.105 36.105 37.105 38.105
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

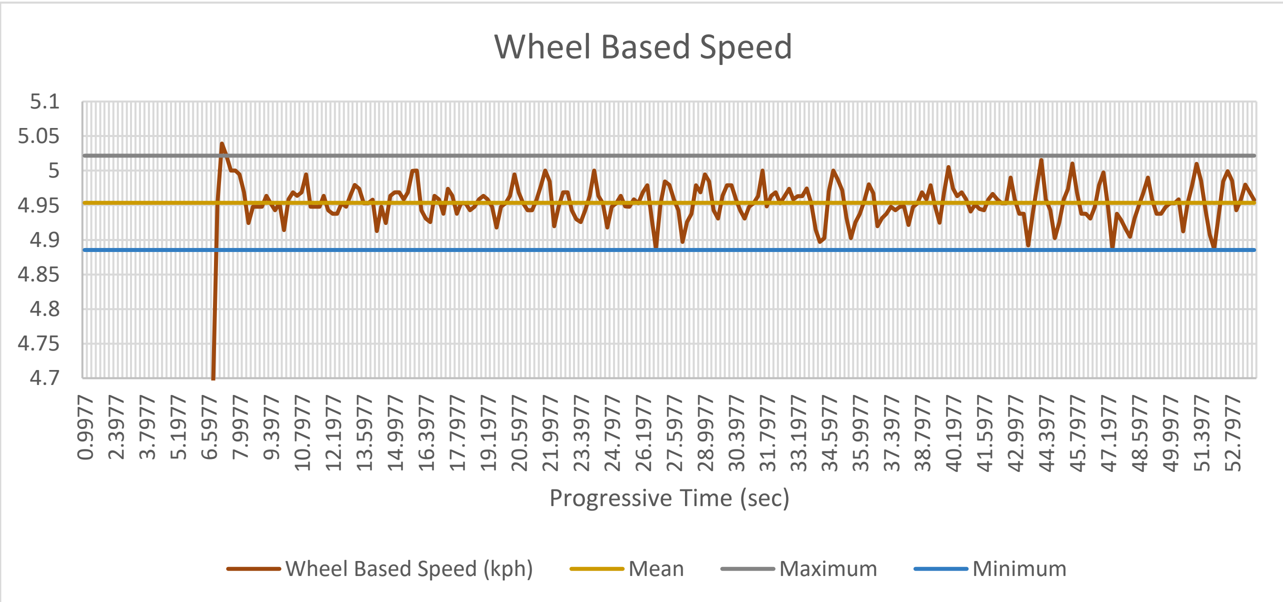
350mm – 5kph

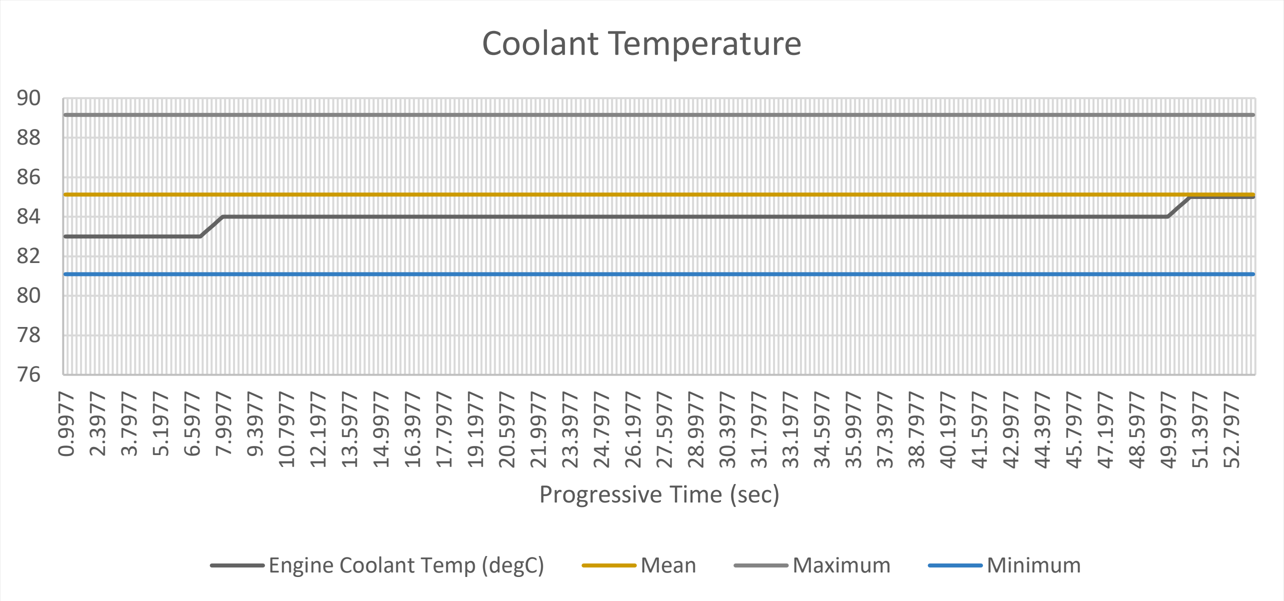

Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1930
1920
1910
1900
1890
1880
1870
1860
1850
Engine RPM
0.9977
2.5977
4.1977
5.7977
7.3977
8.9977
10.5977
12.1977
13.7977
15.3977
16.9977
18.5977
20.1977
21.7977
23.3977
24.9977
26.5977
28.1977
29.7977
31.3977
32.9977
34.5977
36.1977
37.7977
39.3977
40.9977
42.5977
44.1977
45.7977
47.3977
48.9977
50.5977
52.1977
53.7977
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM


Engine Load
85
75
65
55
45
35
25
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

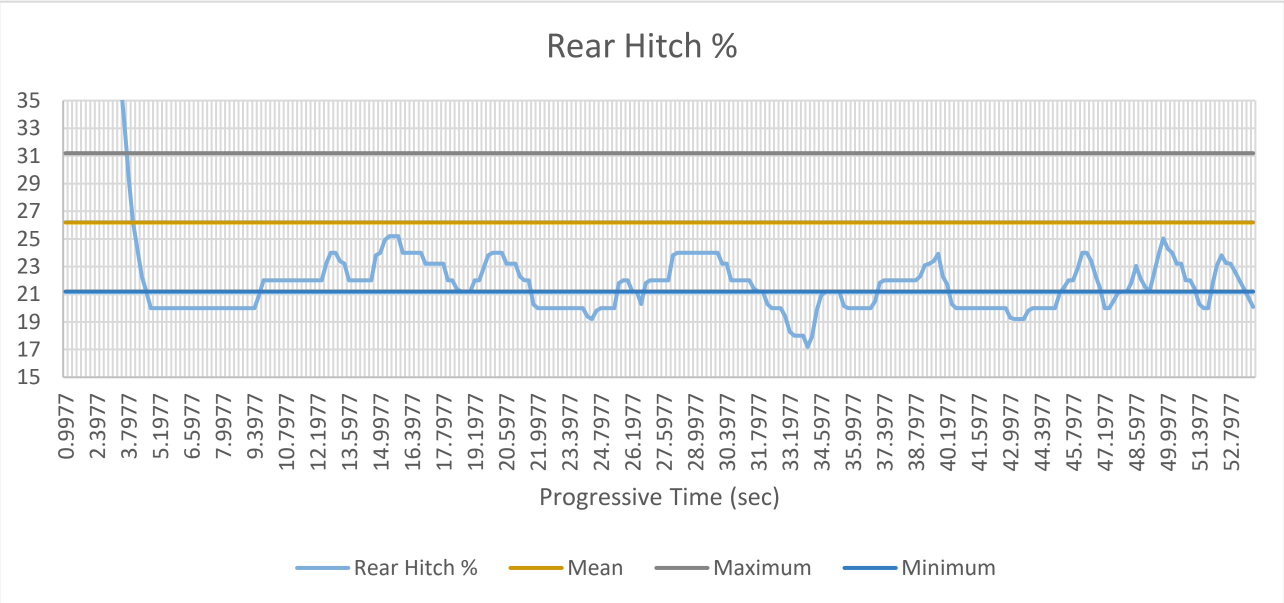

Speed
5.5
5
4.5
4
3.5
3
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
22
20
18
16
14
12
10
8
6
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

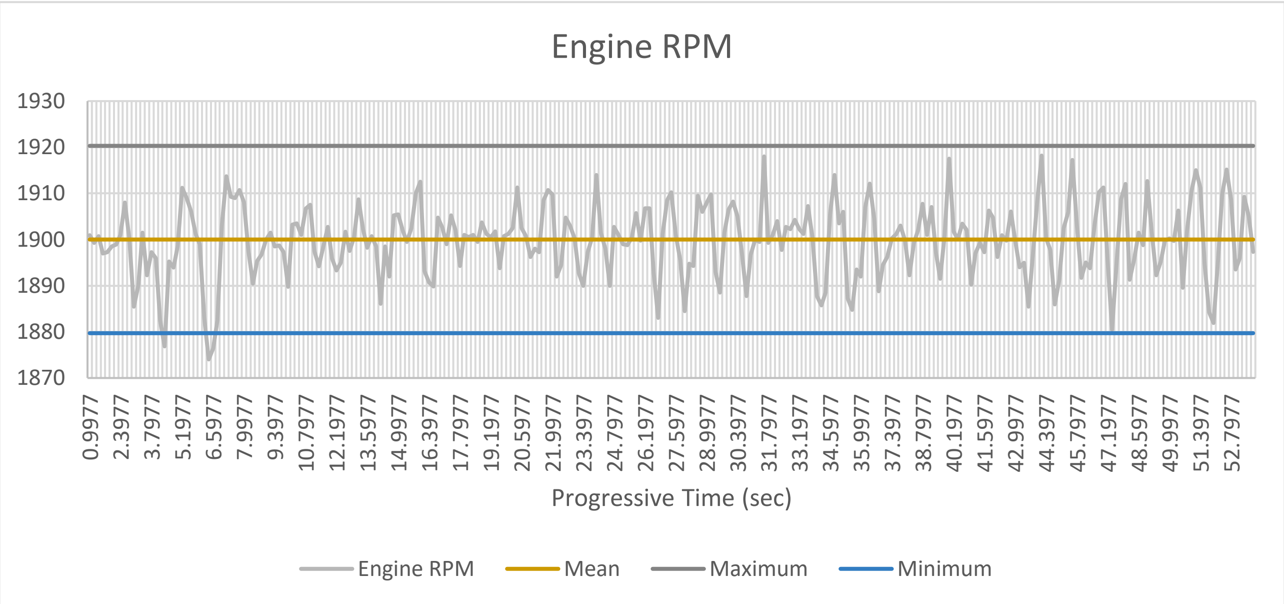

Wheel Based Speed
5.1
5.05
5
4.95
4.9
4.85
4.8
4.75
4.7
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum



Coolant Temperature
90
88
86
84
82
80
78
76
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

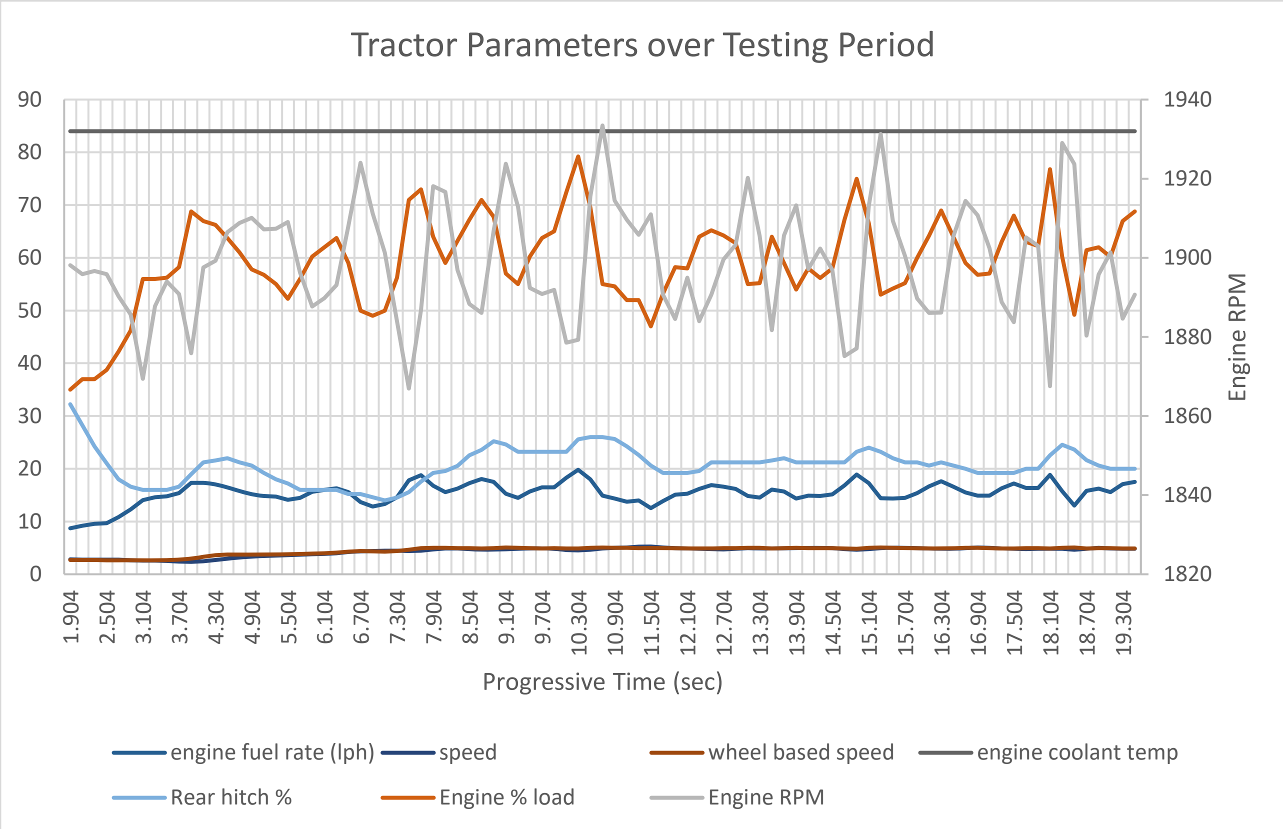


Rear Hitch %
35
33
31
29
27
25
23
21
19
17
15
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

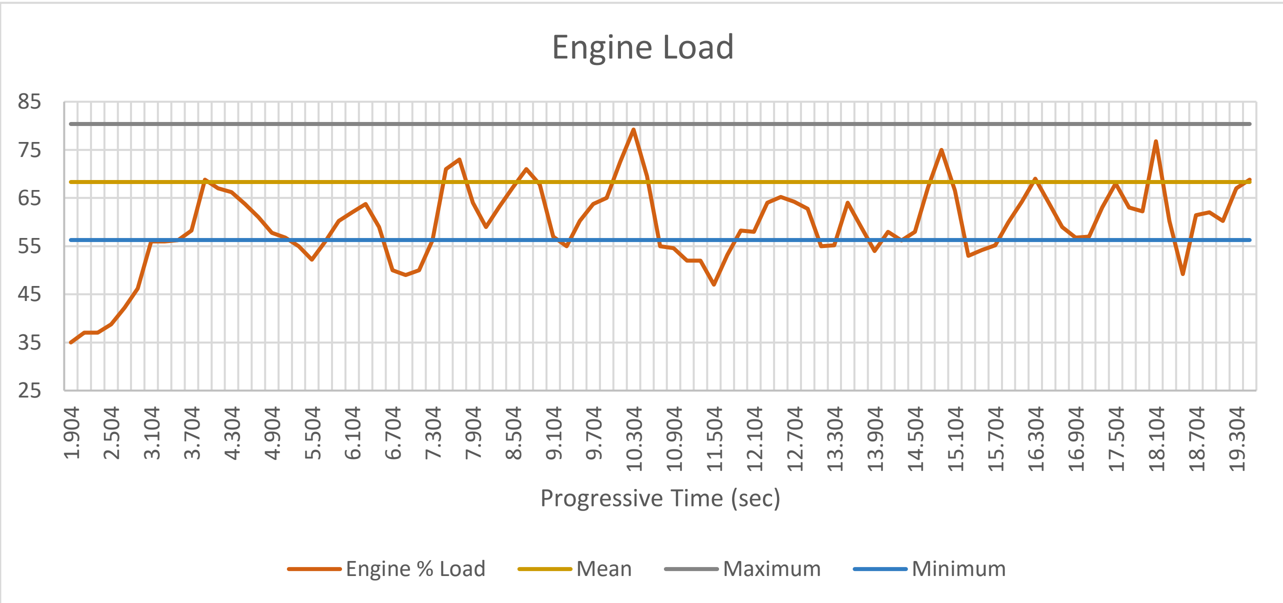


Engine RPM
1930
1920
1910
1900
1890
1880
1870
0.9977
2.3977
3.7977
5.1977
6.5977
7.9977
9.3977
10.7977
12.1977
13.5977
14.9977
16.3977
17.7977
19.1977
20.5977
21.9977
23.3977
24.7977
26.1977
27.5977
28.9977
30.3977
31.7977
33.1977
34.5977
35.9977
37.3977
38.7977
40.1977
41.5977
42.9977
44.3977
45.7977
47.1977
48.5977
49.9977
51.3977
52.7977
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

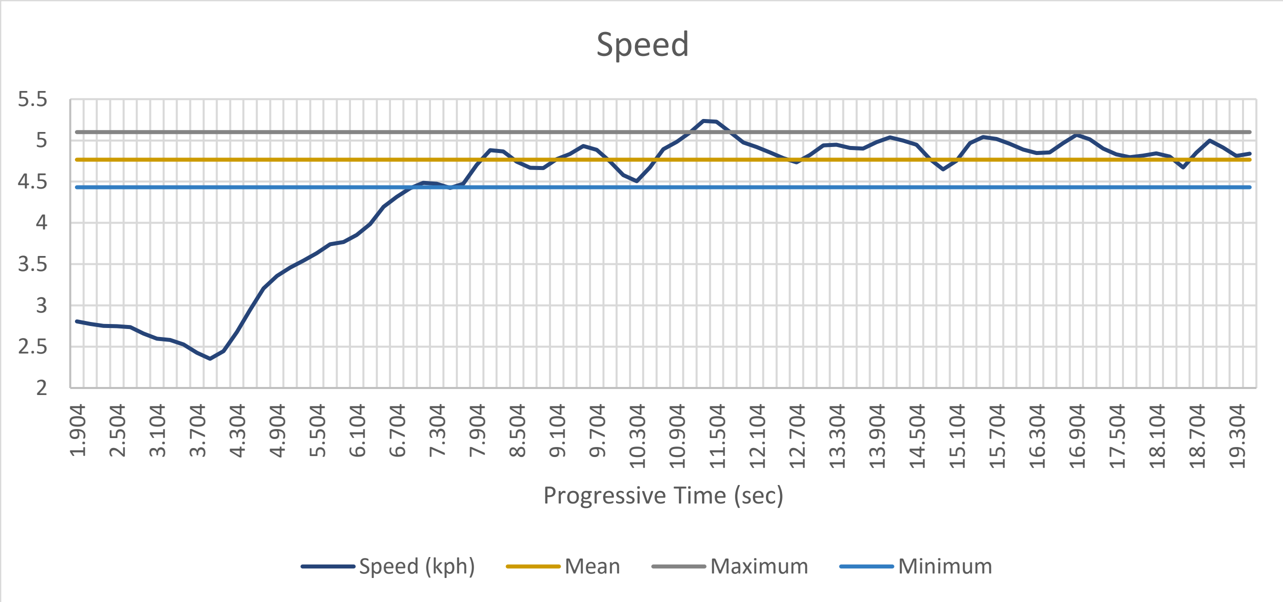
350mm 5kph – 2

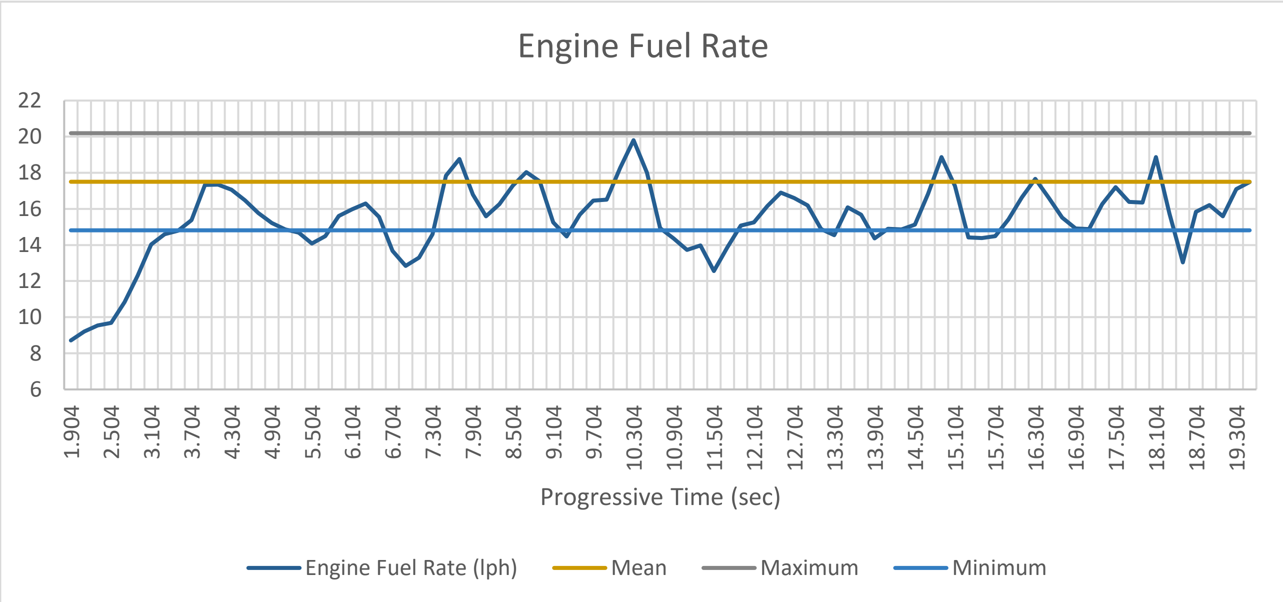


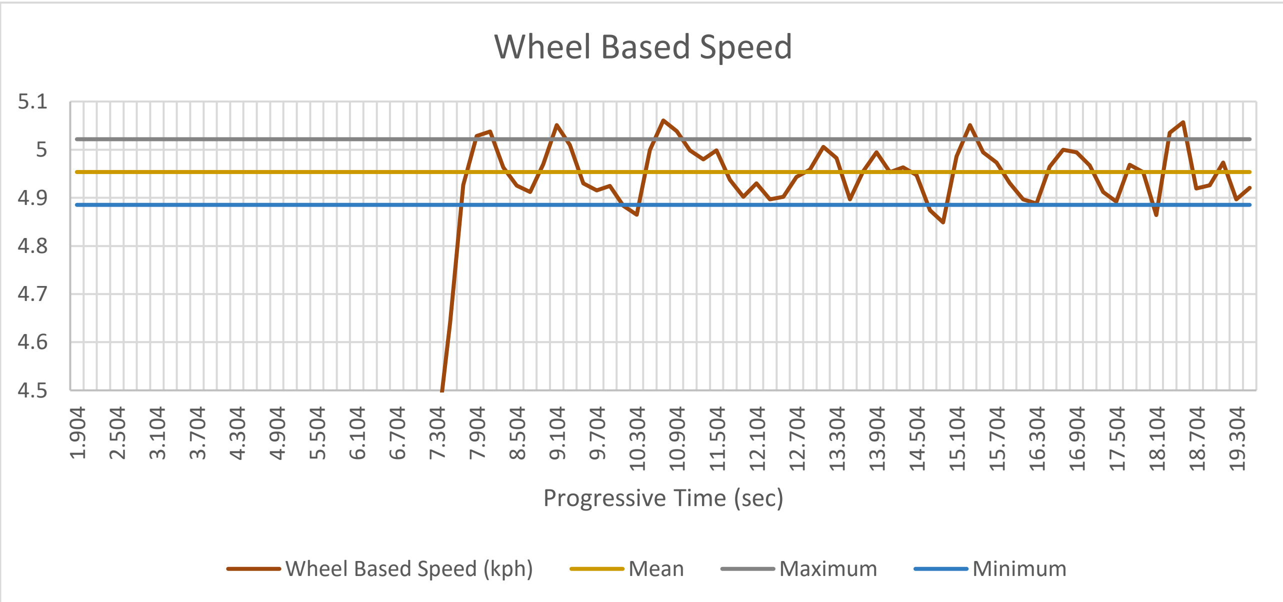
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1940
1920
1900
1880
1860
1840
1820
Engine RPM
1.904
2.504
3.104
3.704
4.304
4.904
5.504
6.104
6.704
7.304
7.904
8.504
9.104
9.704
10.304
10.904
11.504
12.104
12.704
13.304
13.904
14.504
15.104
15.704
16.304
16.904
17.504
18.104
18.704
19.304
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

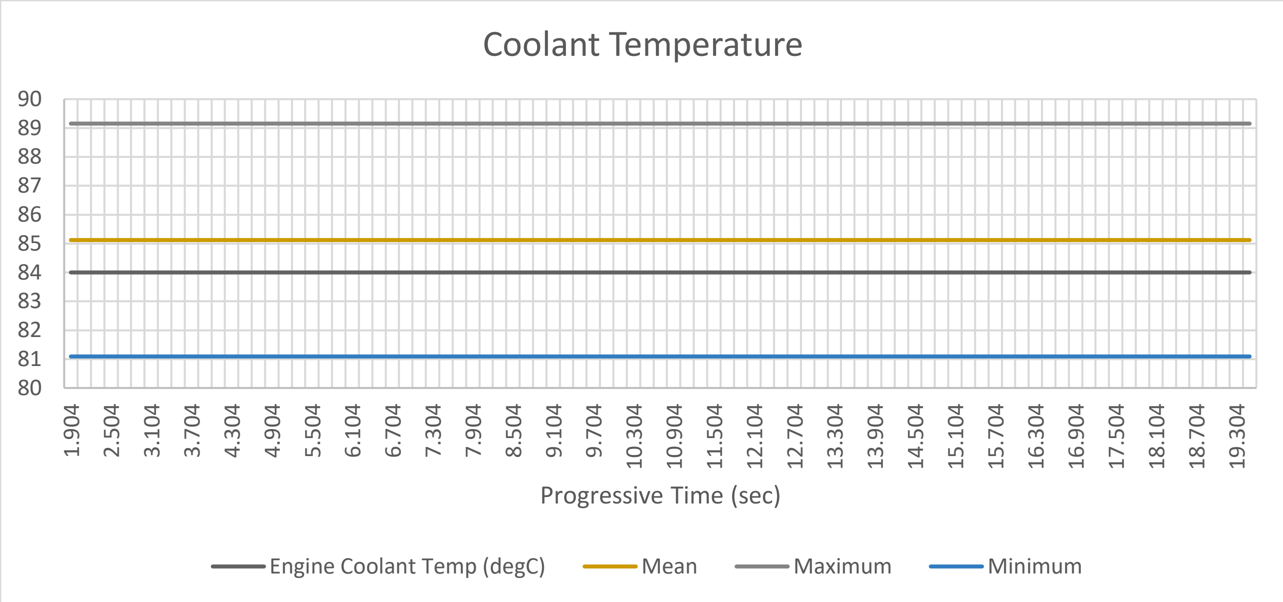


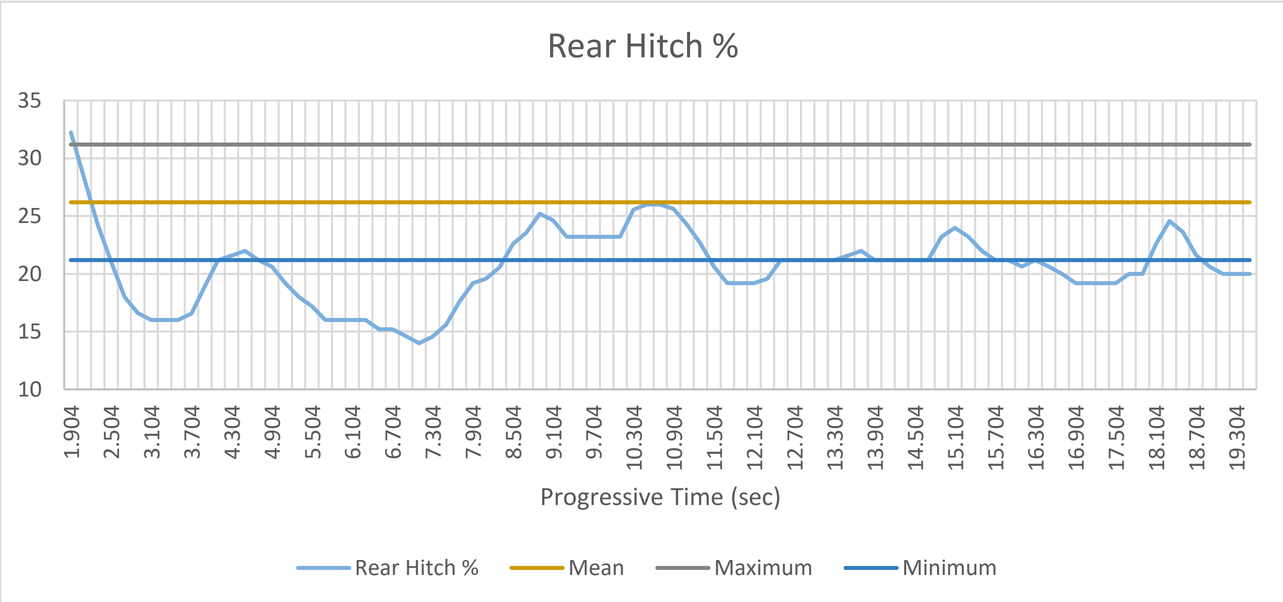
Engine Load
85
75
65
55
45
35
25
1.904
2.504
3.104
3.704
4.304
4.904
5.504
6.104
6.704
7.304
7.904
8.504
9.104
9.704
10.304
10.904
11.504
12.104
12.704
13.304
13.904
14.504
15.104
15.704
16.304
16.904
17.504
18.104
18.704
19.304
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

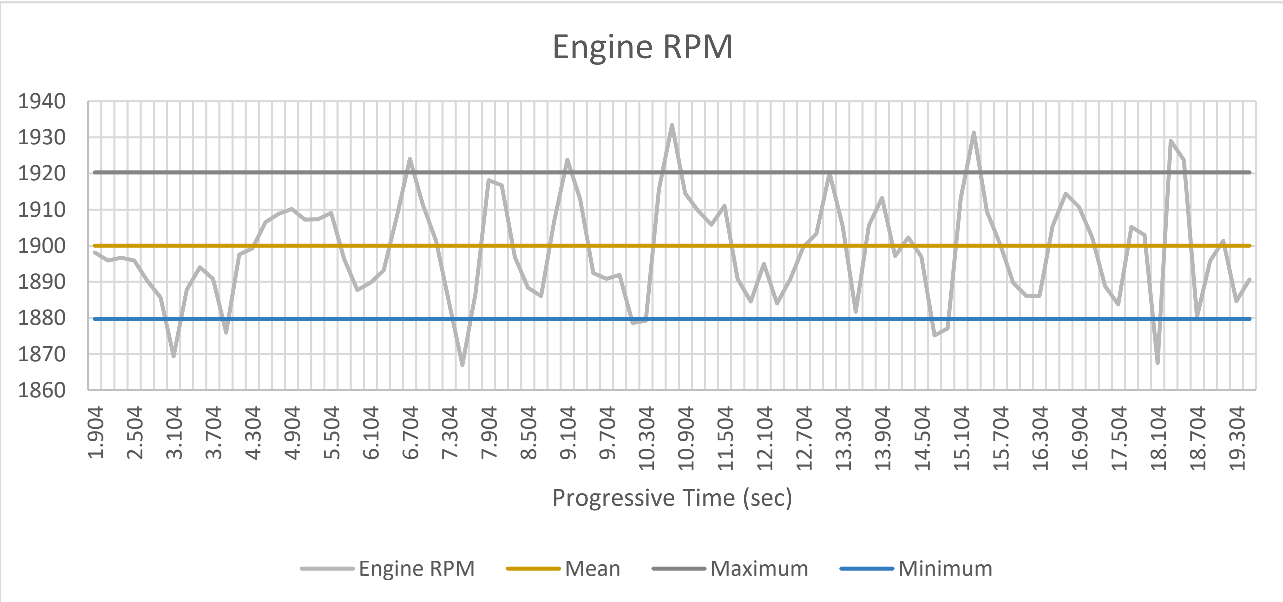

Speed
5.5
5
4.5
4
3.5
3
2.5
2
1.904
2.504
3.104
3.704
4.304
4.904
5.504
6.104
6.704
7.304
7.904
8.504
9.104
9.704
10.304
10.904
11.504
12.104
12.704
13.304
13.904
14.504
15.104
15.704
16.304
16.904
17.504
18.104
18.704
19.304
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
22
20
18
16
14
12
10
8
6
1.904
2.504
3.104
3.704
4.304
4.904
5.504
6.104
6.704
7.304
7.904
8.504
9.104
9.704
10.304
10.904
11.504
12.104
12.704
13.304
13.904
14.504
15.104
15.704
16.304
16.904
17.504
18.104
18.704
19.304
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

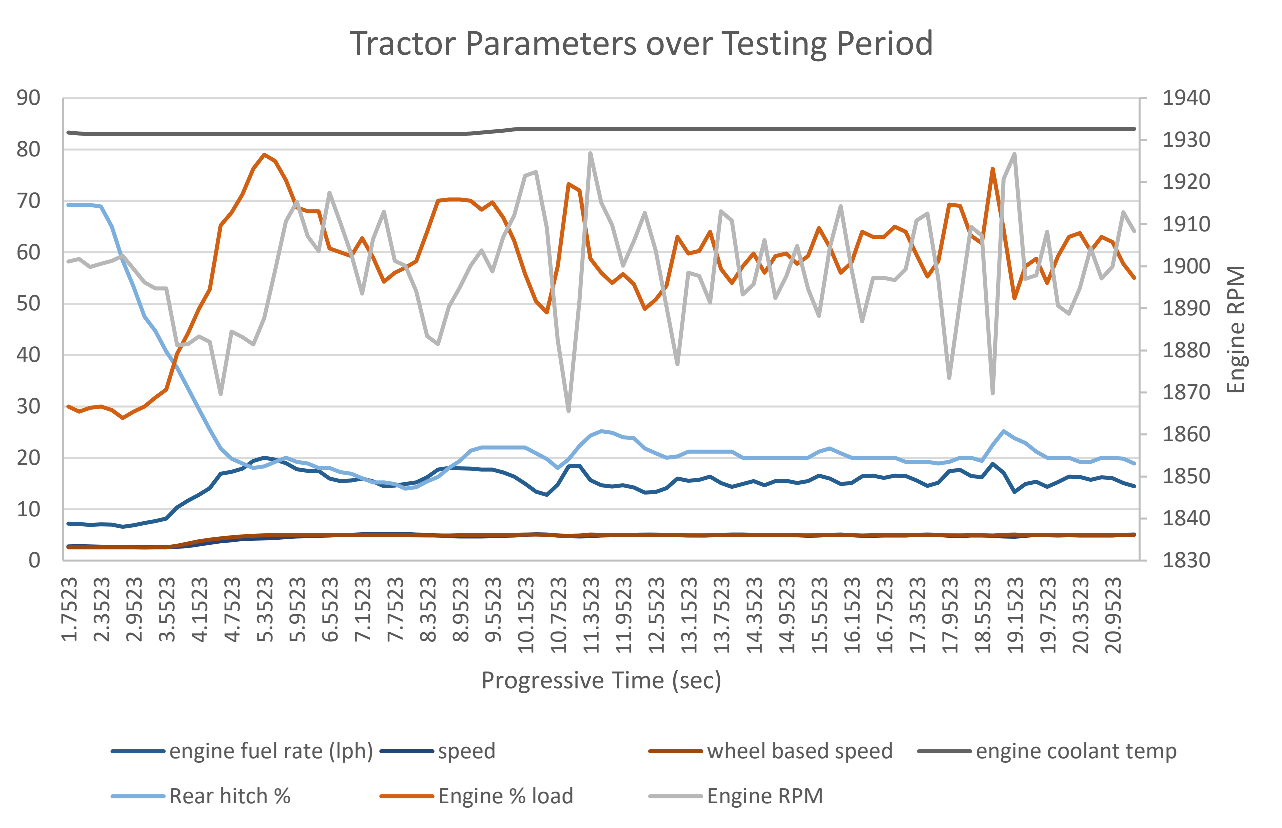

Wheel Based Speed
5.1
5
4.9
4.8
4.7
4.6
4.5
1.904
2.504
3.104
3.704
4.304
4.904
5.504
6.104
6.704
7.304
7.904
8.504
9.104
9.704
10.304
10.904
11.504
12.104
12.704
13.304
13.904
14.504
15.104
15.704
16.304
16.904
17.504
18.104
18.704
19.304
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

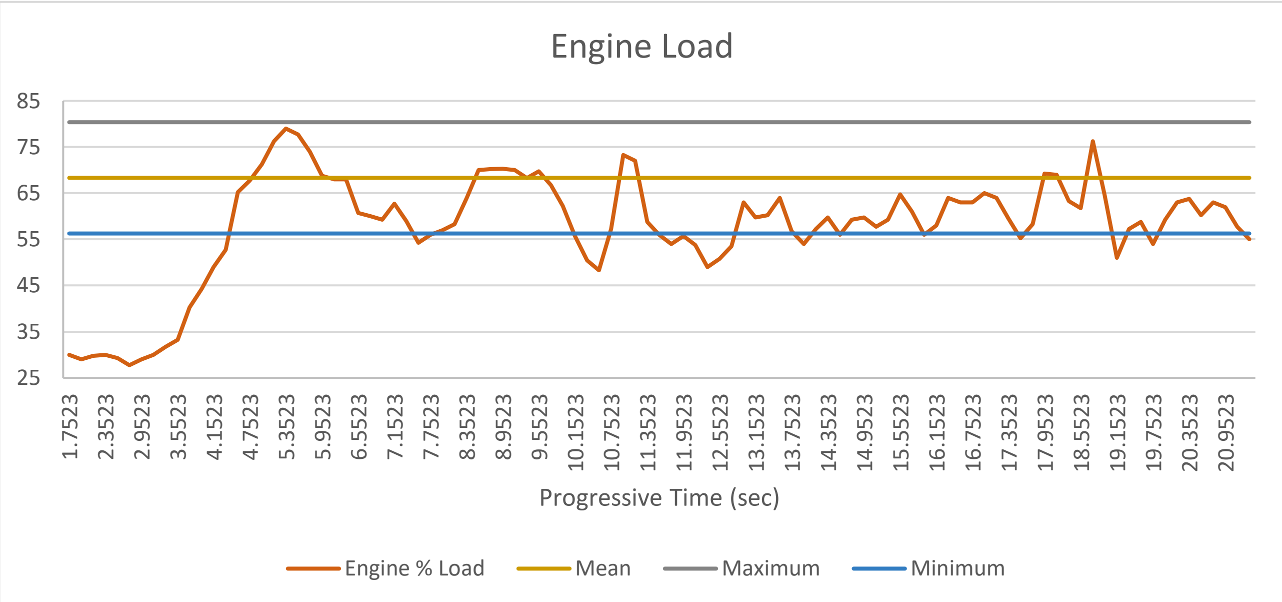

Coolant Temperature
90
89
88
87
86
85
84
83
82
81
80
1.904 2.504 3.104 3.704 4.304 4.904 5.504 6.104 6.704 7.304 7.904 8.504 9.104 9.704 10.304 10.904 11.504 12.104 12.704 13.304 13.904 14.504 15.104 15.704 16.304 16.904 17.504 18.104 18.704 19.304
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

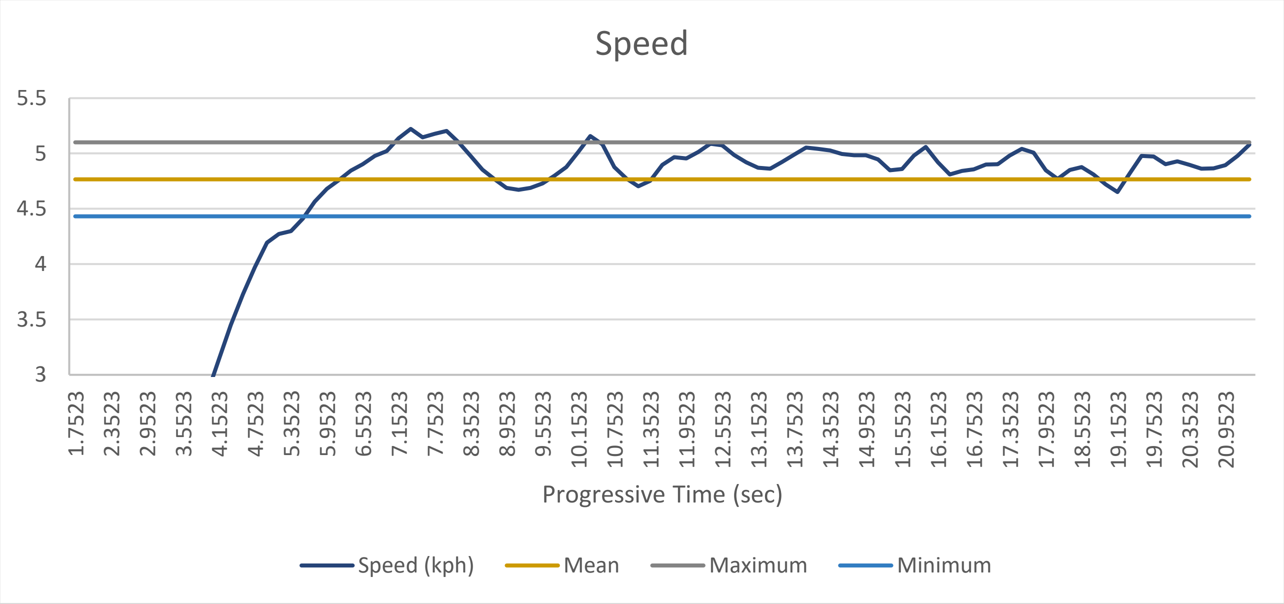

Rear Hitch %
35
30
25
20
15
10
1.904 2.504 3.104 3.704 4.304 4.904 5.504 6.104 6.704 7.304 7.904 8.504 9.104 9.704 10.304 10.904 11.504 12.104 12.704 13.304 13.904 14.504 15.104 15.704 16.304 16.904 17.504 18.104 18.704 19.304
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1860
1.904 2.504 3.104 3.704 4.304 4.904 5.504 6.104 6.704 7.304 7.904 8.504 9.104 9.704 10.304 10.904 11.504 12.104 12.704 13.304 13.904 14.504 15.104 15.704 16.304 16.904 17.504 18.104 18.704 19.304
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

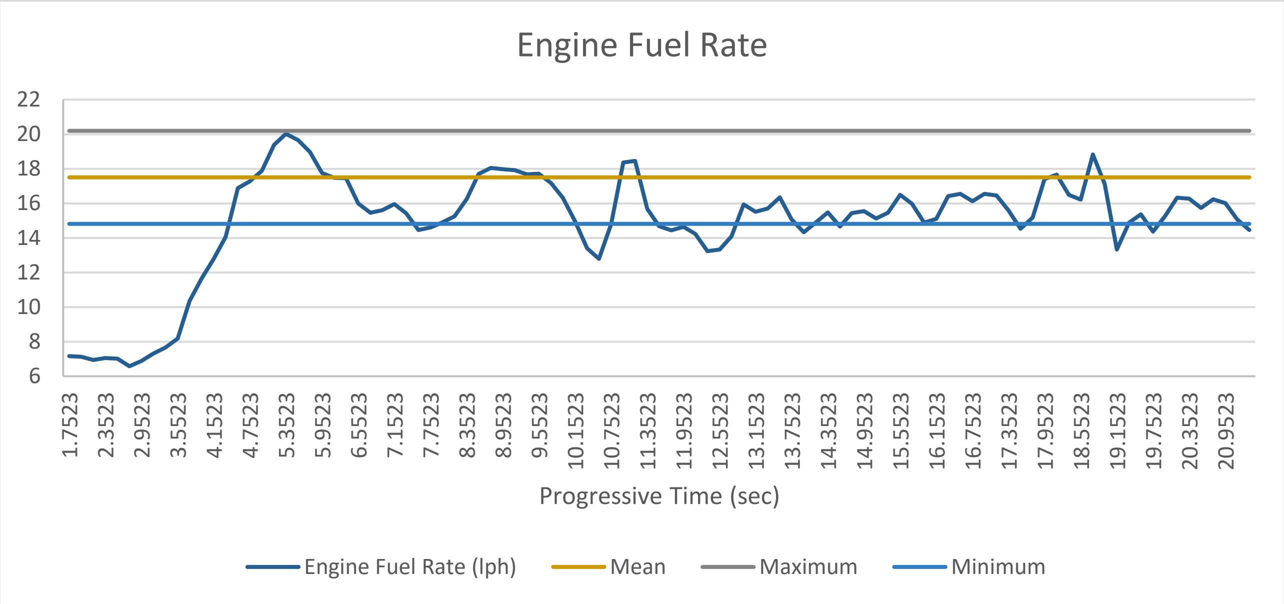
350mm – 5kph – half cut pin



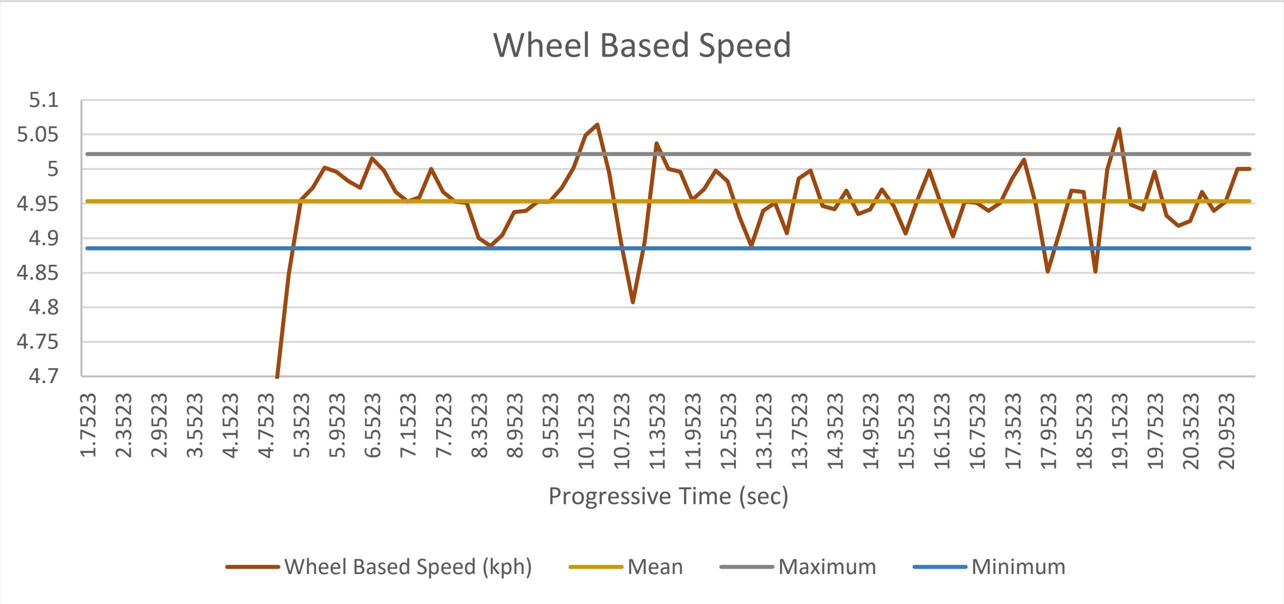




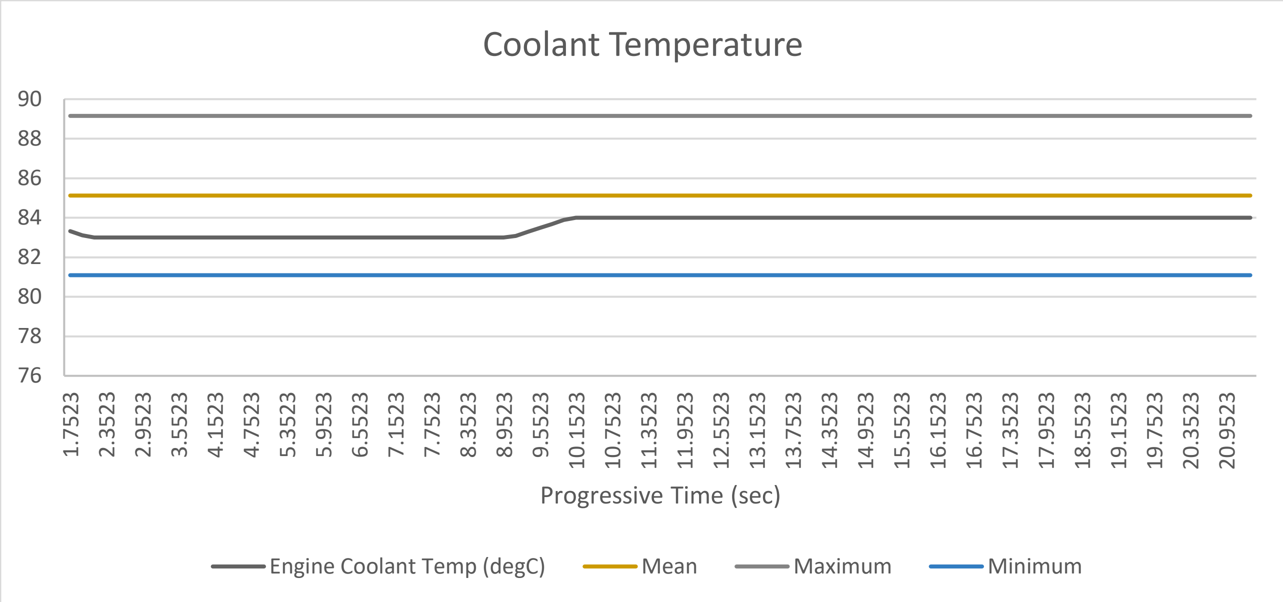
Speed
5.5
5
4.5
4
3.5
3
1.7523
2.3523
2.9523
3.5523
4.1523
4.7523
5.3523
5.9523
6.5523
7.1523
7.7523
8.3523
8.9523
9.5523
10.1523
10.7523
11.3523
11.9523
12.5523
13.1523
13.7523
14.3523
14.9523
15.5523
16.1523
16.7523
17.3523
17.9523
18.5523
19.1523
19.7523
20.3523
20.9523
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum

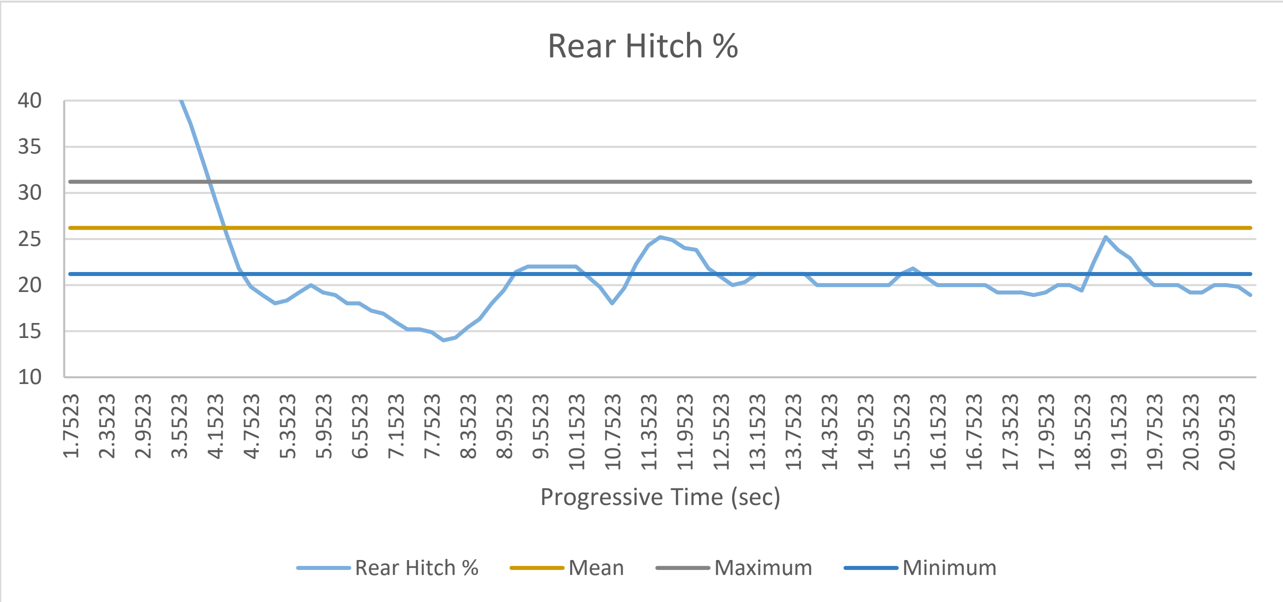


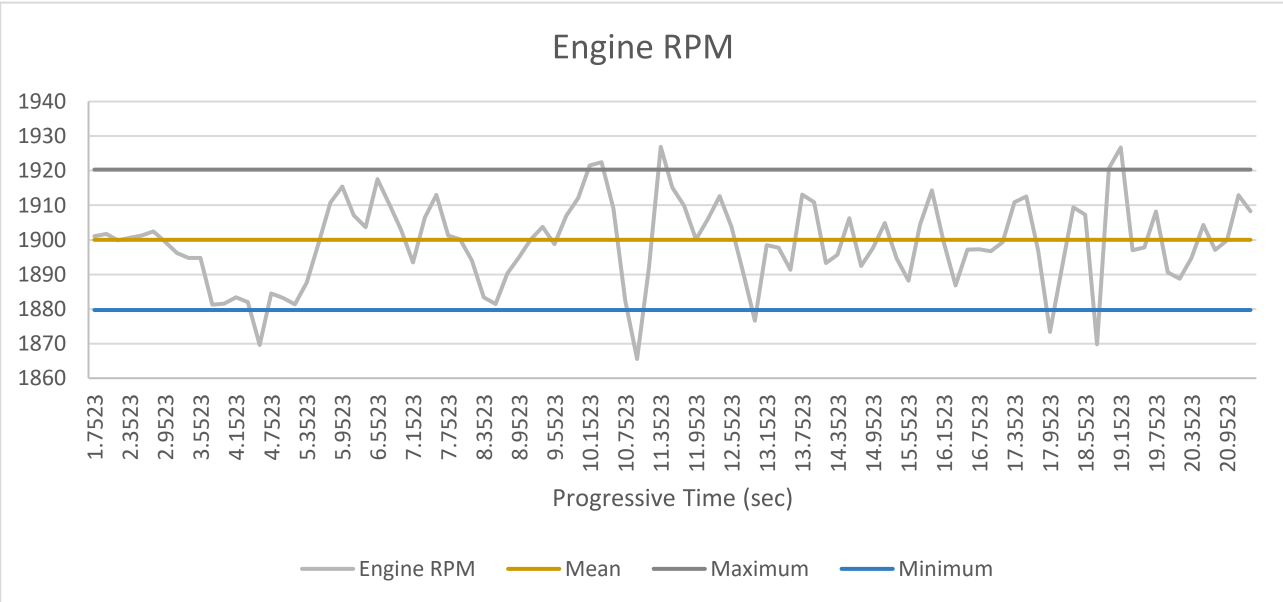
Engine Fuel Rate
22
20
18
16
14
12
10
8
6
1.7523
2.3523
2.9523
3.5523
4.1523
4.7523
5.3523
5.9523
6.5523
7.1523
7.7523
8.3523
8.9523
9.5523
10.1523
10.7523
11.3523
11.9523
12.5523
13.1523
13.7523
14.3523
14.9523
15.5523
16.1523
16.7523
17.3523
17.9523
18.5523
19.1523
19.7523
20.3523
20.9523
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum



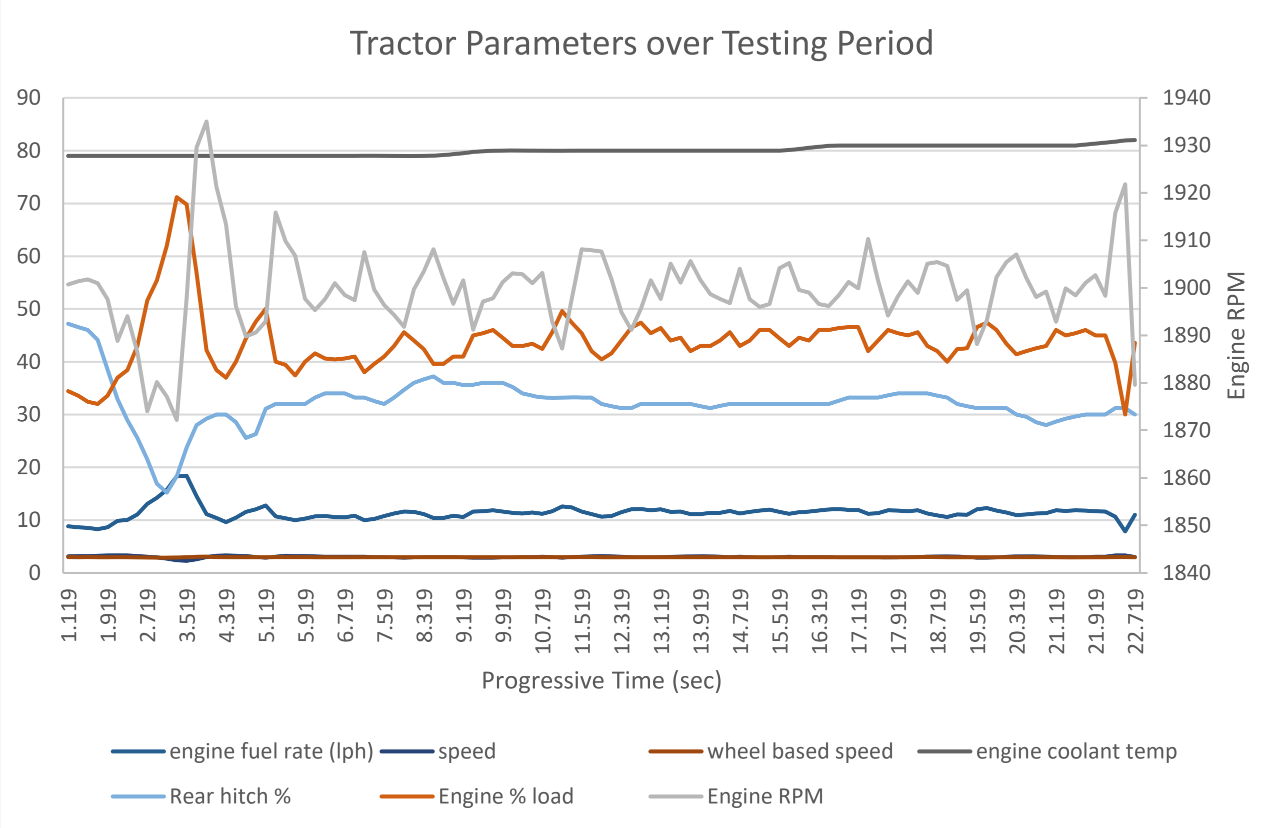
Wheel Based Speed
5.1
5.05
5
4.95
4.9
4.85
4.8
4.75
4.7
1.7523
2.3523
2.9523
3.5523
4.1523
4.7523
5.3523
5.9523
6.5523
7.1523
7.7523
8.3523
8.9523
9.5523
10.1523
10.7523
11.3523
11.9523
12.5523
13.1523
13.7523
14.3523
14.9523
15.5523
16.1523
16.7523
17.3523
17.9523
18.5523
19.1523
19.7523
20.3523
20.9523
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
88
86
84
82
80
78
76
1.7523 2.3523 2.9523 3.5523 4.1523 4.7523 5.3523 5.9523 6.5523 7.1523 7.7523 8.3523 8.9523 9.5523 10.1523 10.7523 11.3523 11.9523 12.5523 13.1523 13.7523 14.3523 14.9523 15.5523 16.1523 16.7523 17.3523 17.9523 18.5523 19.1523 19.7523 20.3523 20.9523
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

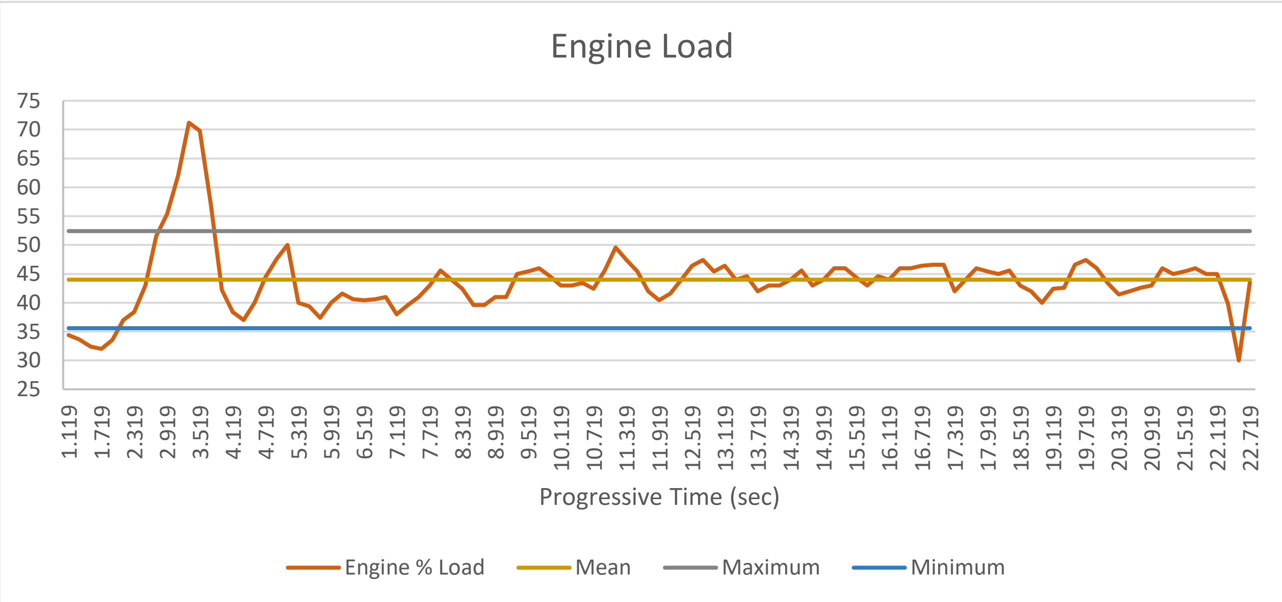

Rear Hitch %
40
35
30
25
20
15
10
1.7523 2.3523 2.9523 3.5523 4.1523 4.7523 5.3523 5.9523 6.5523 7.1523 7.7523 8.3523 8.9523 9.5523 10.1523 10.7523 11.3523 11.9523 12.5523 13.1523 13.7523 14.3523 14.9523 15.5523 16.1523 16.7523 17.3523 17.9523 18.5523 19.1523 19.7523 20.3523 20.9523
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1860
1.7523 2.3523 2.9523 3.5523 4.1523 4.7523 5.3523 5.9523 6.5523 7.1523 7.7523 8.3523 8.9523 9.5523 10.1523 10.7523 11.3523 11.9523 12.5523 13.1523 13.7523 14.3523 14.9523 15.5523 16.1523 16.7523 17.3523 17.9523 18.5523 19.1523 19.7523 20.3523 20.9523
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

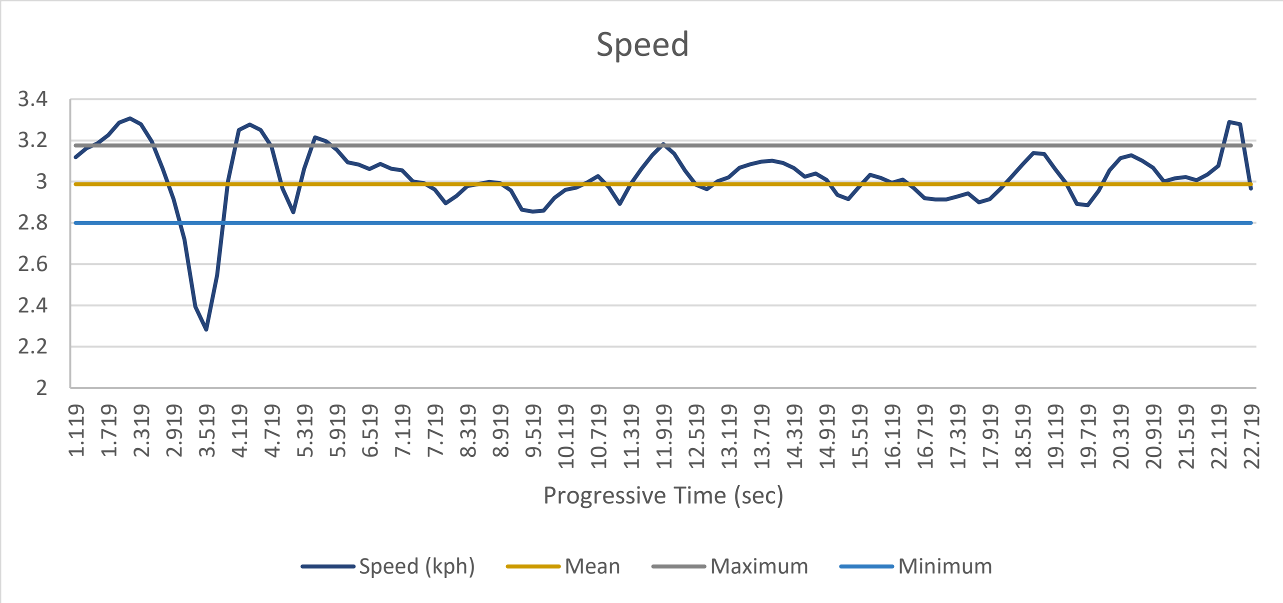
300mm – 3kph

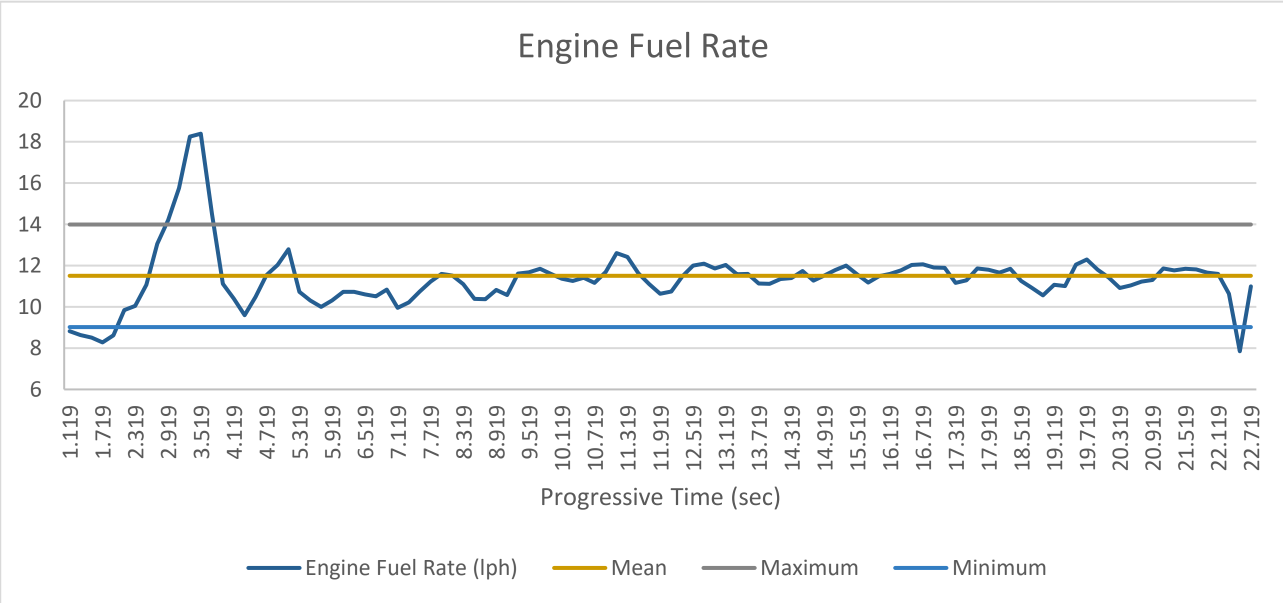


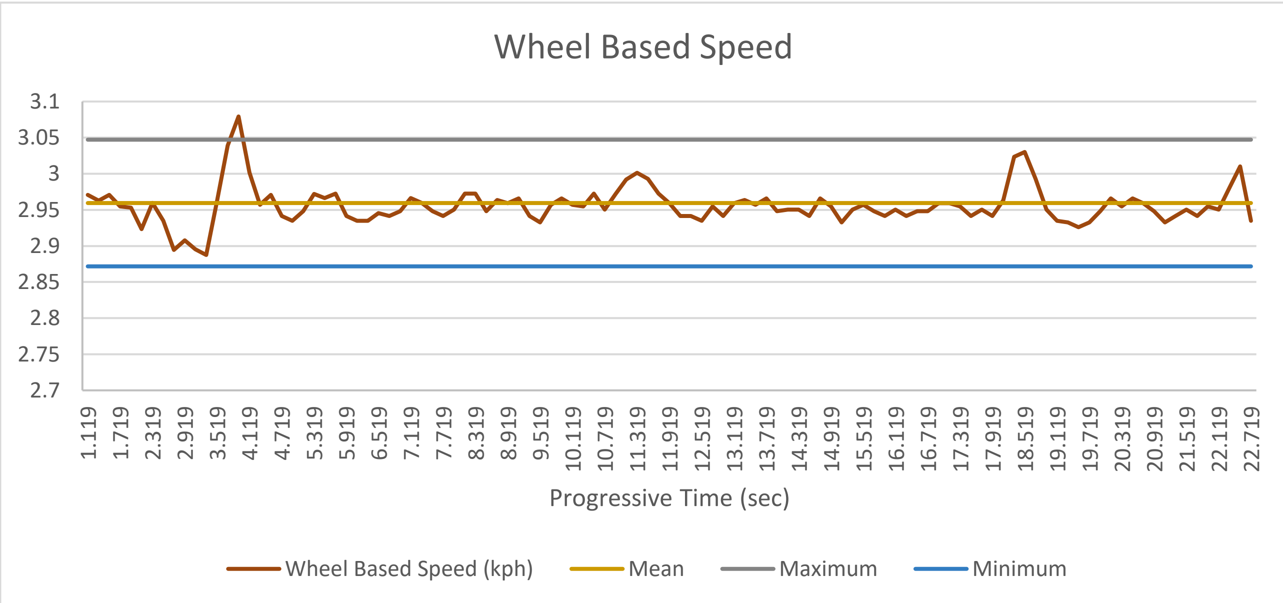
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
Engine RPM
1.119
1.919
2.719
3.519
4.319
5.119
5.919
6.719
7.519
8.319
9.119
9.919
10.719
11.519
12.319
13.119
13.919
14.719
15.519
16.319
17.119
17.919
18.719
19.519
20.319
21.119
21.919
22.719
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

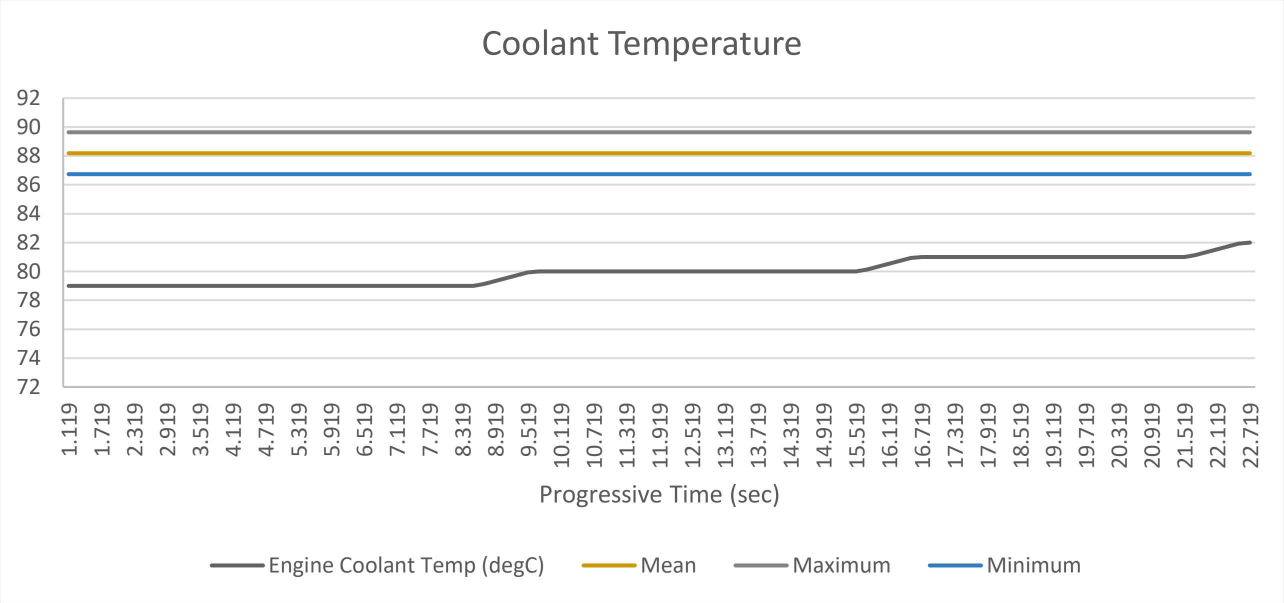


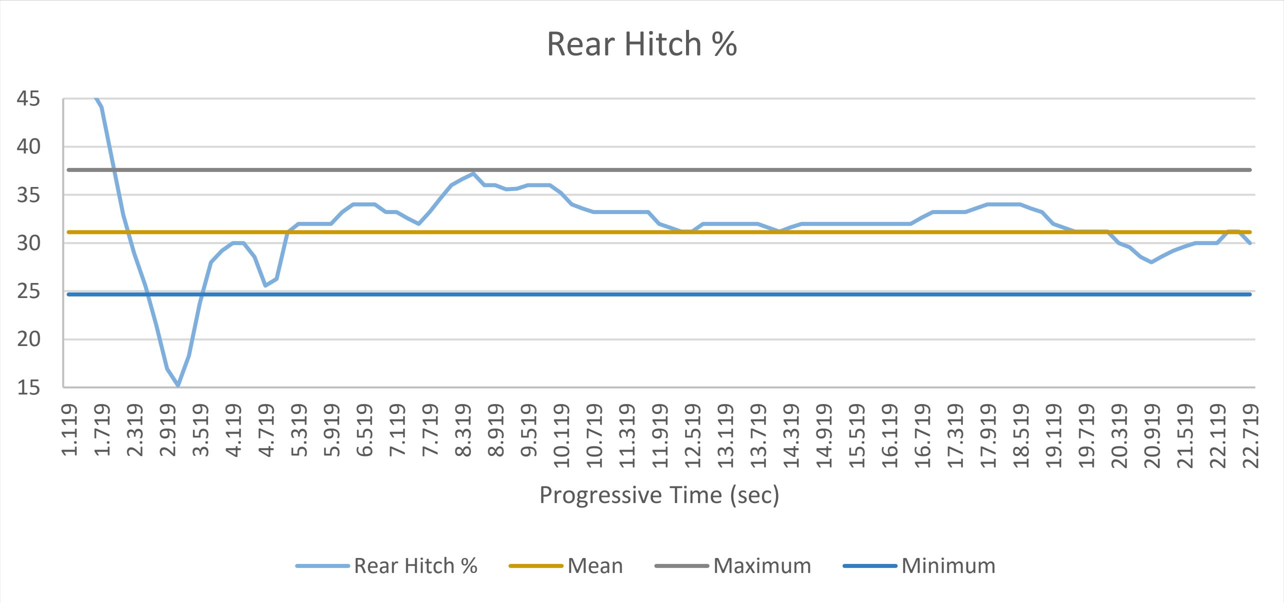
Engine Load
75
70
65
60
55
50
45
40
35
30
25
1.119
1.719
2.319
2.919
3.519
4.119
4.719
5.319
5.919
6.519
7.119
7.719
8.319
8.919
9.519
10.119
10.719
11.319
11.919
12.519
13.119
13.719
14.319
14.919
15.519
16.119
16.719
17.319
17.919
18.519
19.119
19.719
20.319
20.919
21.519
22.119
22.719
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

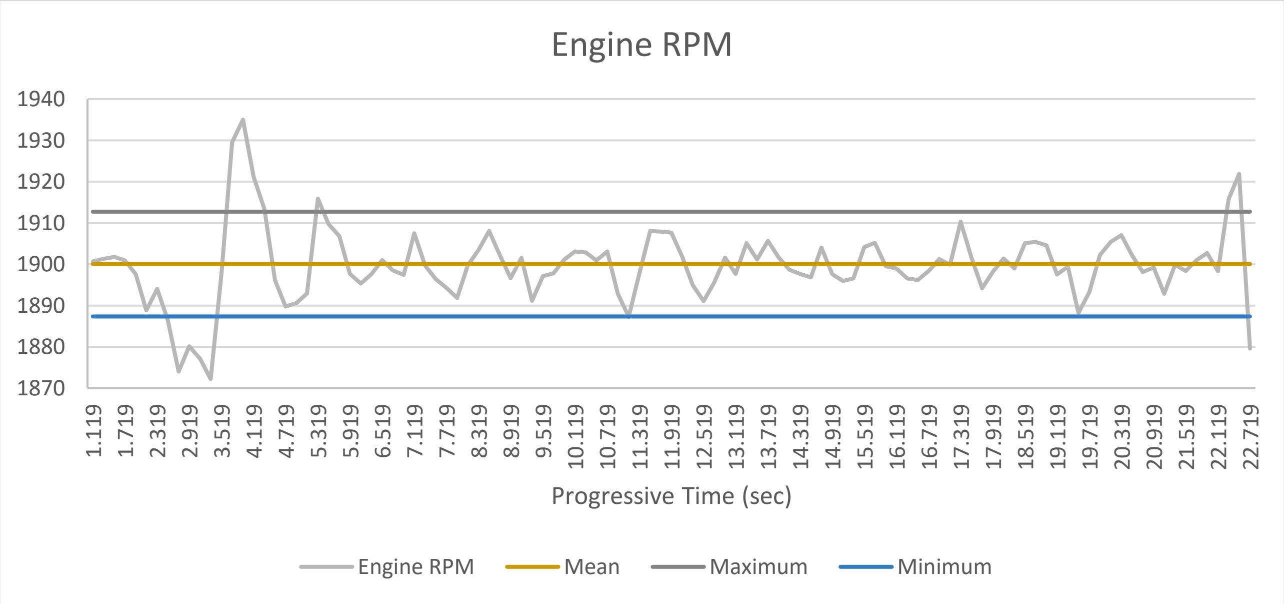

Speed
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.119
1.719
2.319
2.919
3.519
4.119
4.719
5.319
5.919
6.519
7.119
7.719
8.319
8.919
9.519
10.119
10.719
11.319
11.919
12.519
13.119
13.719
14.319
14.919
15.519
16.119
16.719
17.319
17.919
18.519
19.119
19.719
20.319
20.919
21.519
22.119
22.719
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
20
18
16
14
12
10
8
6
1.119
1.719
2.319
2.919
3.519
4.119
4.719
5.319
5.919
6.519
7.119
7.719
8.319
8.919
9.519
10.119
10.719
11.319
11.919
12.519
13.119
13.719
14.319
14.919
15.519
16.119
16.719
17.319
17.919
18.519
19.119
19.719
20.319
20.919
21.519
22.119
22.719
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

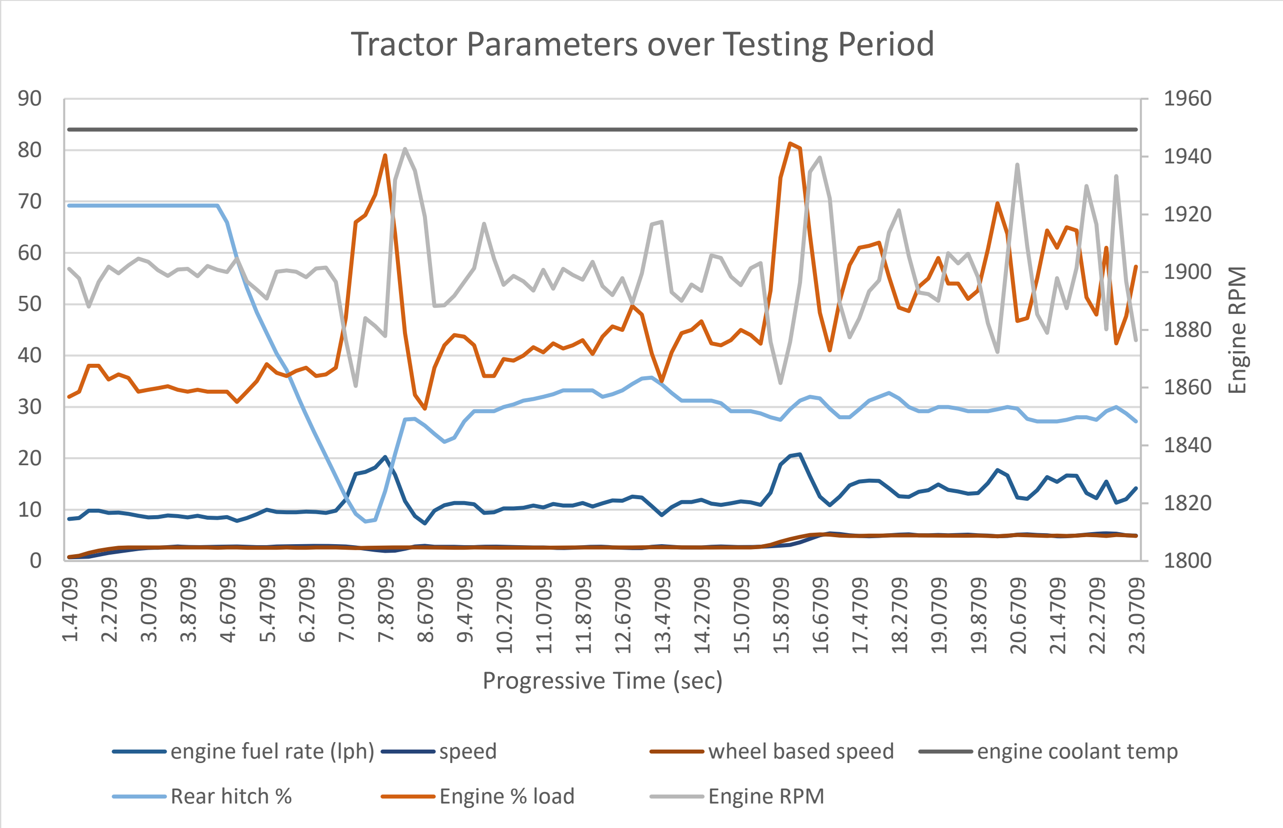

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
1.119
1.719
2.319
2.919
3.519
4.119
4.719
5.319
5.919
6.519
7.119
7.719
8.319
8.919
9.519
10.119
10.719
11.319
11.919
12.519
13.119
13.719
14.319
14.919
15.519
16.119
16.719
17.319
17.919
18.519
19.119
19.719
20.319
20.919
21.519
22.119
22.719
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
92
90
88
86
84
82
80
78
76
74
72
1.119 1.719 2.319 2.919 3.519 4.119 4.719 5.319 5.919 6.519 7.119 7.719 8.319 8.919 9.519 10.119 10.719 11.319 11.919 12.519 13.119 13.719 14.319 14.919 15.519 16.119 16.719 17.319 17.919 18.519 19.119 19.719 20.319 20.919 21.519 22.119 22.719
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

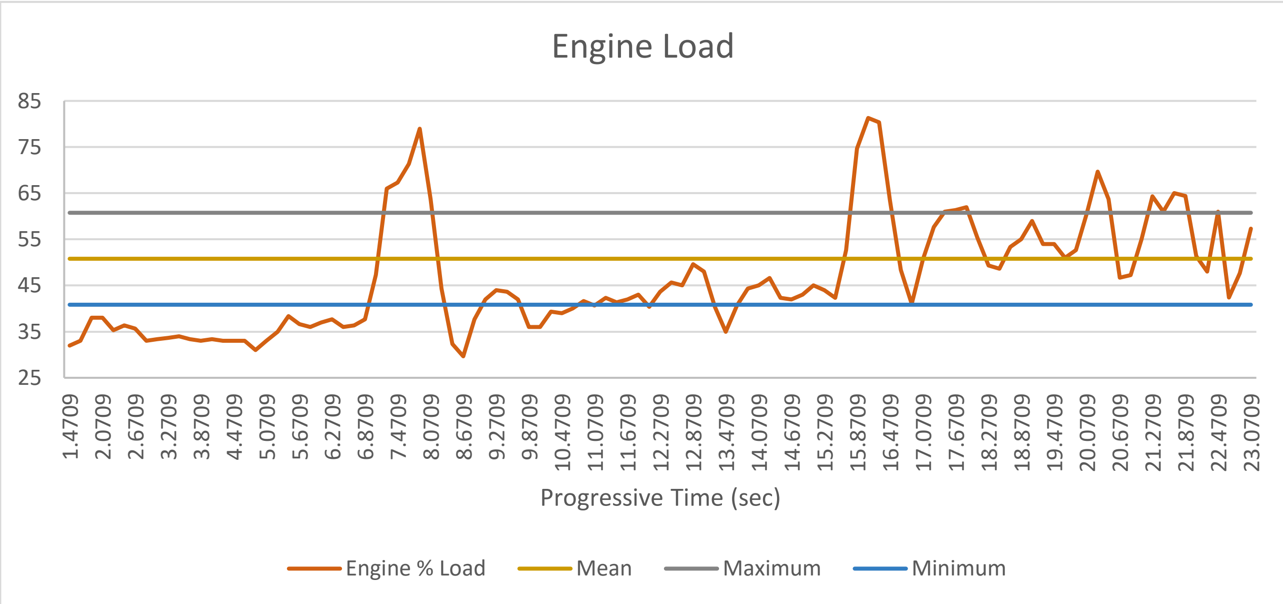

Rear Hitch %
45
40
35
30
25
20
15
1.119 1.719 2.319 2.919 3.519 4.119 4.719 5.319 5.919 6.519 7.119 7.719 8.319 8.919 9.519 10.119 10.719 11.319 11.919 12.519 13.119 13.719 14.319 14.919 15.519 16.119 16.719 17.319 17.919 18.519 19.119 19.719 20.319 20.919 21.519 22.119 22.719
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1.119 1.719 2.319 2.919 3.519 4.119 4.719 5.319 5.919 6.519 7.119 7.719 8.319 8.919 9.519 10.119 10.719 11.319 11.919 12.519 13.119 13.719 14.319 14.919 15.519 16.119 16.719 17.319 17.919 18.519 19.119 19.719 20.319 20.919 21.519 22.119 22.719
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

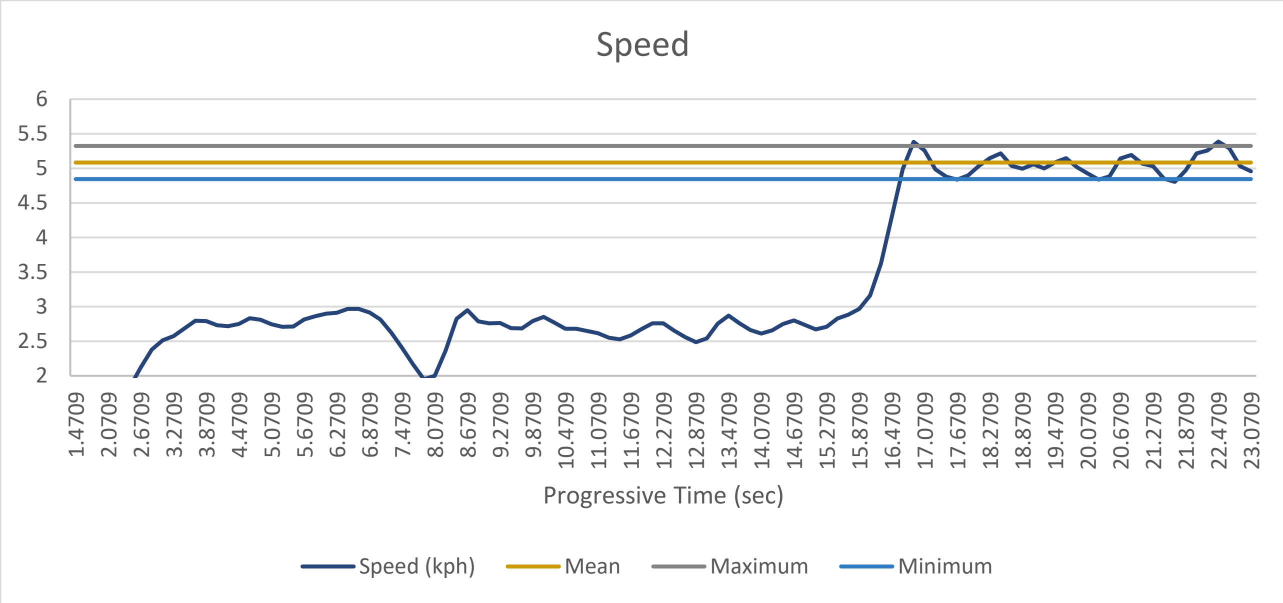
300mm – 5kph

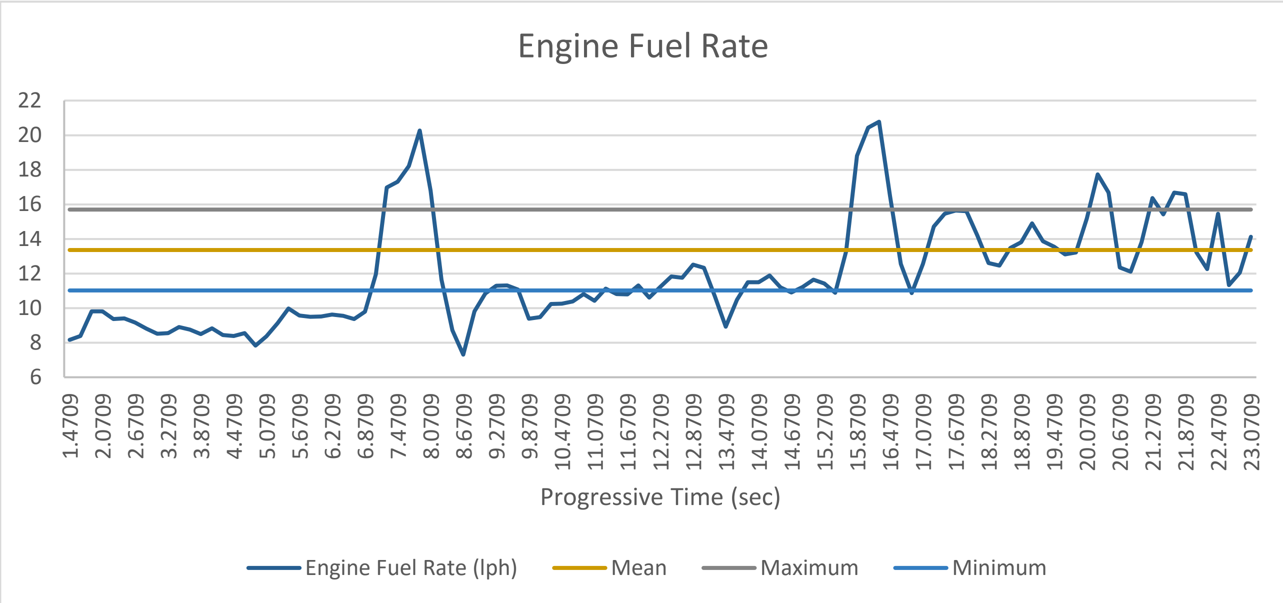


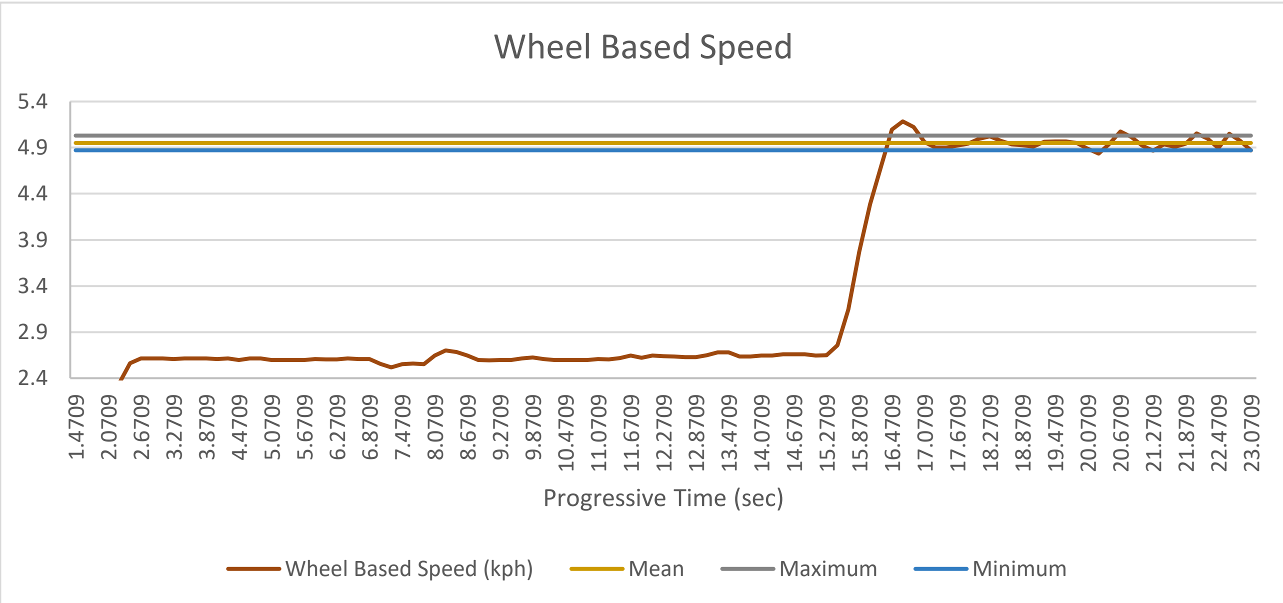
Tractor Parameters over Testing Period
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

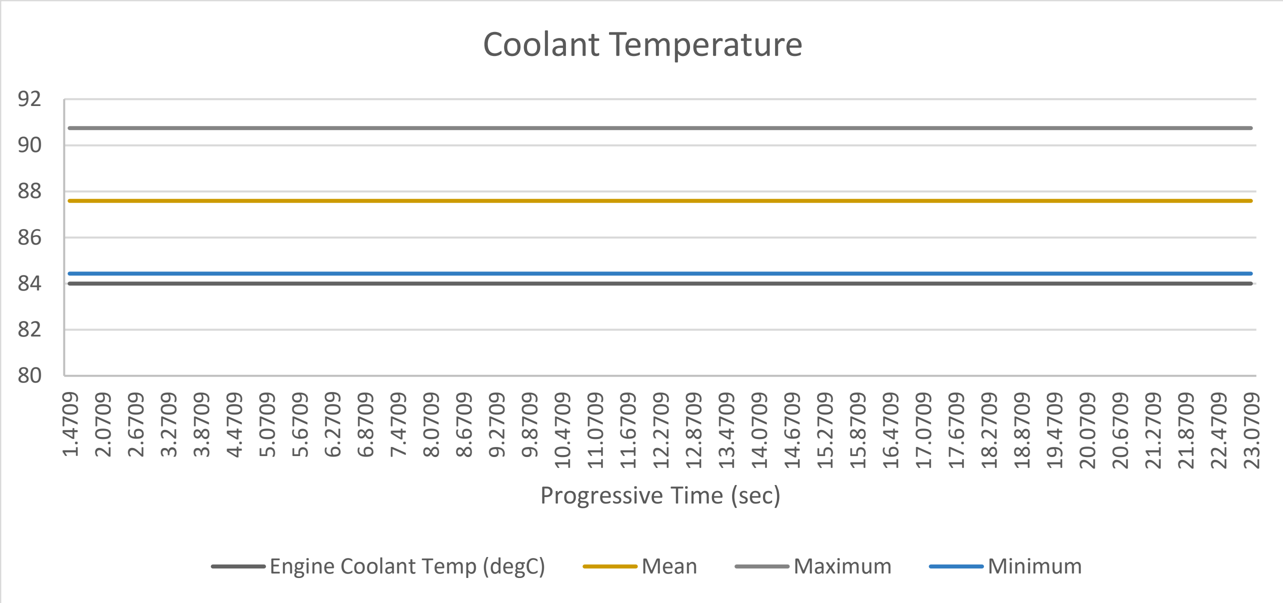


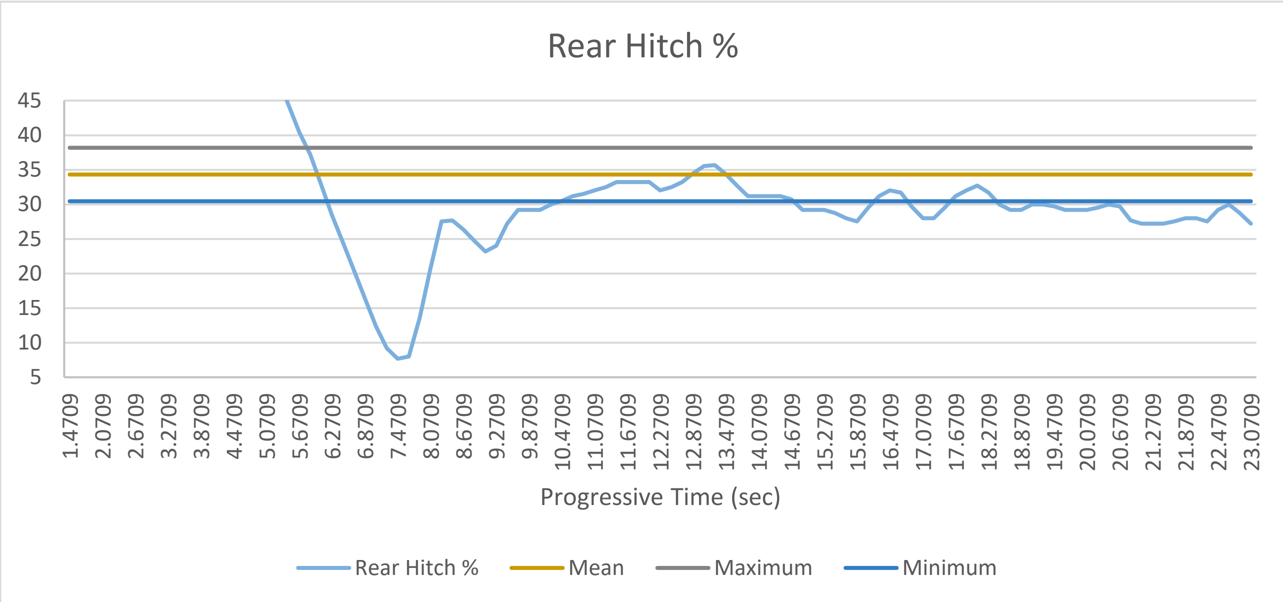
Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

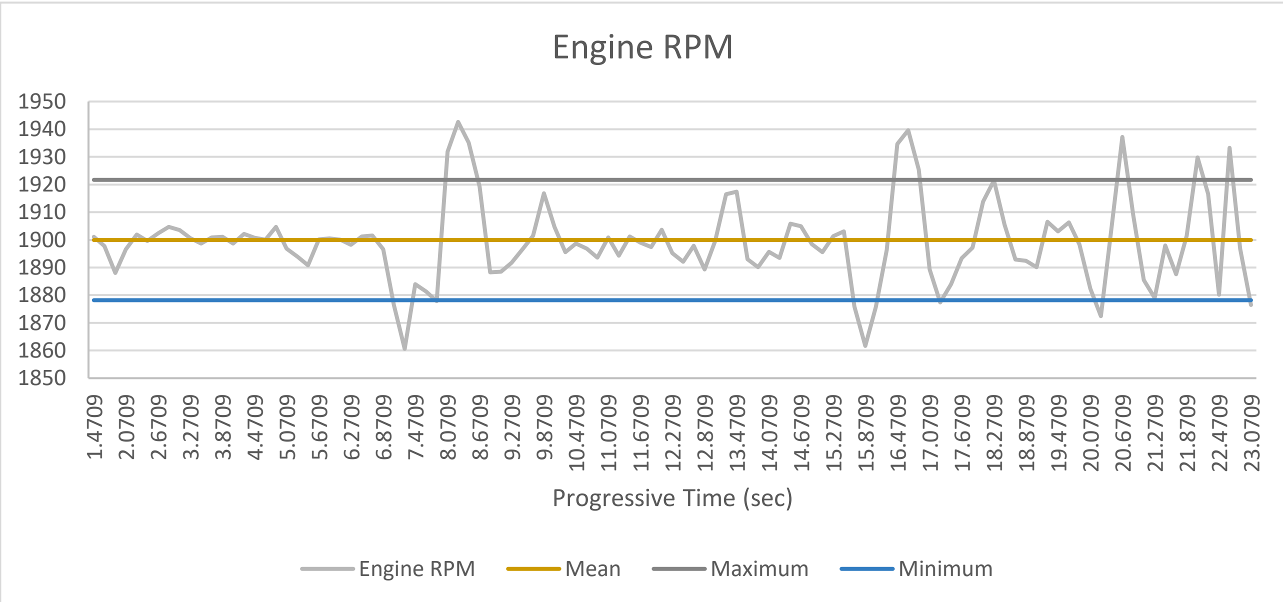

Speed
6
5.5
5
4.5
4
3.5
3
2.5
2
1.4709 2.0709 2.6709 3.2709 3.8709 4.4709 5.0709 5.6709 6.2709 6.8709 7.4709 8.0709 8.6709 9.2709 9.8709 10.4709 11.0709 11.6709 12.2709 12.8709 13.4709 14.0709 14.6709 15.2709 15.8709 16.4709 17.0709 17.6709 18.2709 18.8709 19.4709 20.0709 20.6709 21.2709 21.8709 22.4709 23.0709
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
22
20
18
16
14
12
10
8
6
1.4709 2.0709 2.6709 3.2709 3.8709 4.4709 5.0709 5.6709 6.2709 6.8709 7.4709 8.0709 8.6709 9.2709 9.8709 10.4709 11.0709 11.6709 12.2709 12.8709 13.4709 14.0709 14.6709 15.2709 15.8709 16.4709 17.0709 17.6709 18.2709 18.8709 19.4709 20.0709 20.6709 21.2709 21.8709 22.4709 23.0709
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

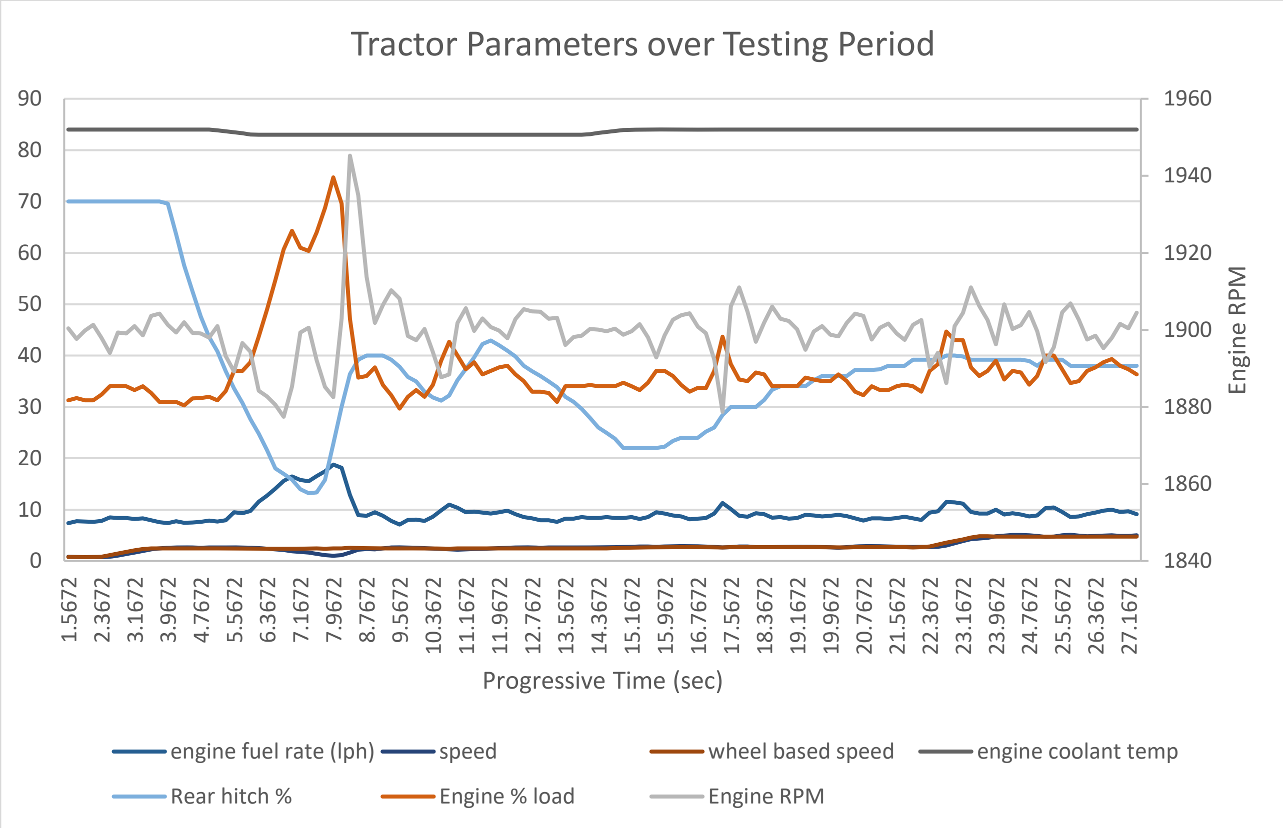

Wheel Based Speed
5.4
4.9
4.4
3.9
3.4
2.9
2.4
1.4709 2.0709 2.6709 3.2709 3.8709 4.4709 5.0709 5.6709 6.2709 6.8709 7.4709 8.0709 8.6709 9.2709 9.8709 10.4709 11.0709 11.6709 12.2709 12.8709 13.4709 14.0709 14.6709 15.2709 15.8709 16.4709 17.0709 17.6709 18.2709 18.8709 19.4709 20.0709 20.6709 21.2709 21.8709 22.4709 23.0709
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
92
90
88
86
84
82
80
1.4709
2.0709
2.6709
3.2709
3.8709
4.4709
5.0709
5.6709
6.2709
6.8709
7.4709
8.0709
8.6709
9.2709
9.8709
10.4709
11.0709
11.6709
12.2709
12.8709
13.4709
14.0709
14.6709
15.2709
15.8709
16.4709
17.0709
17.6709
18.2709
18.8709
19.4709
20.0709
20.6709
21.2709
21.8709
22.4709
23.0709
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

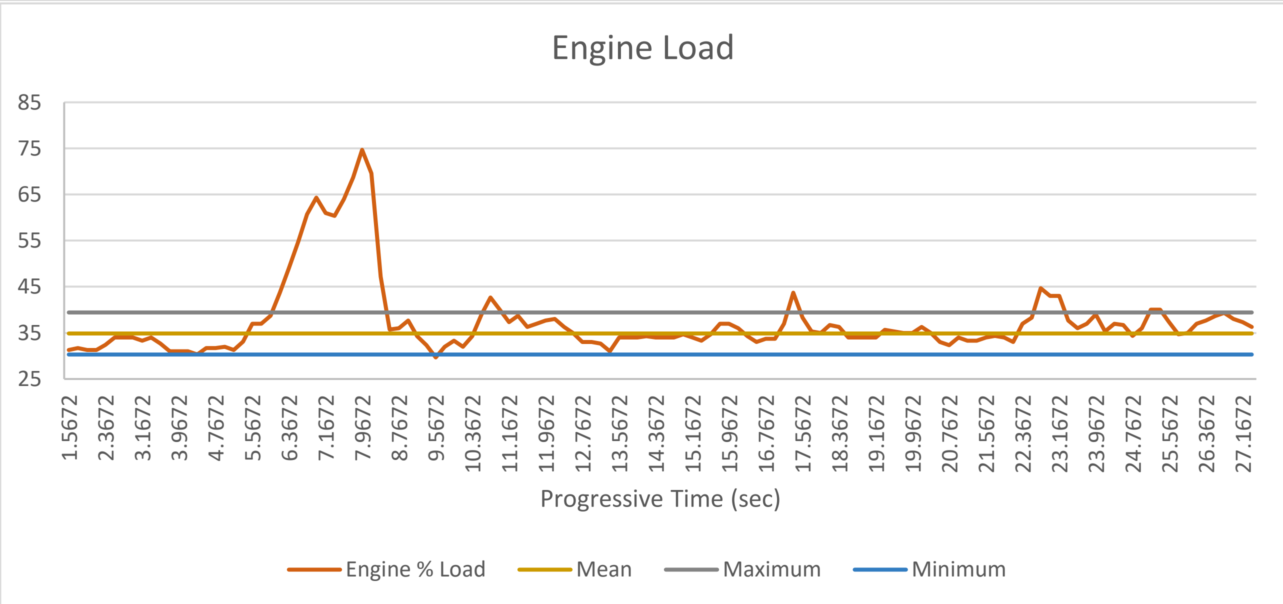

Rear Hitch %
45
40
35
30
25
20
15
10
5
1.4709
2.0709
2.6709
3.2709
3.8709
4.4709
5.0709
5.6709
6.2709
6.8709
7.4709
8.0709
8.6709
9.2709
9.8709
10.4709
11.0709
11.6709
12.2709
12.8709
13.4709
14.0709
14.6709
15.2709
15.8709
16.4709
17.0709
17.6709
18.2709
18.8709
19.4709
20.0709
20.6709
21.2709
21.8709
22.4709
23.0709
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1950
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1.4709
2.0709
2.6709
3.2709
3.8709
4.4709
5.0709
5.6709
6.2709
6.8709
7.4709
8.0709
8.6709
9.2709
9.8709
10.4709
11.0709
11.6709
12.2709
12.8709
13.4709
14.0709
14.6709
15.2709
15.8709
16.4709
17.0709
17.6709
18.2709
18.8709
19.4709
20.0709
20.6709
21.2709
21.8709
22.4709
23.0709
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

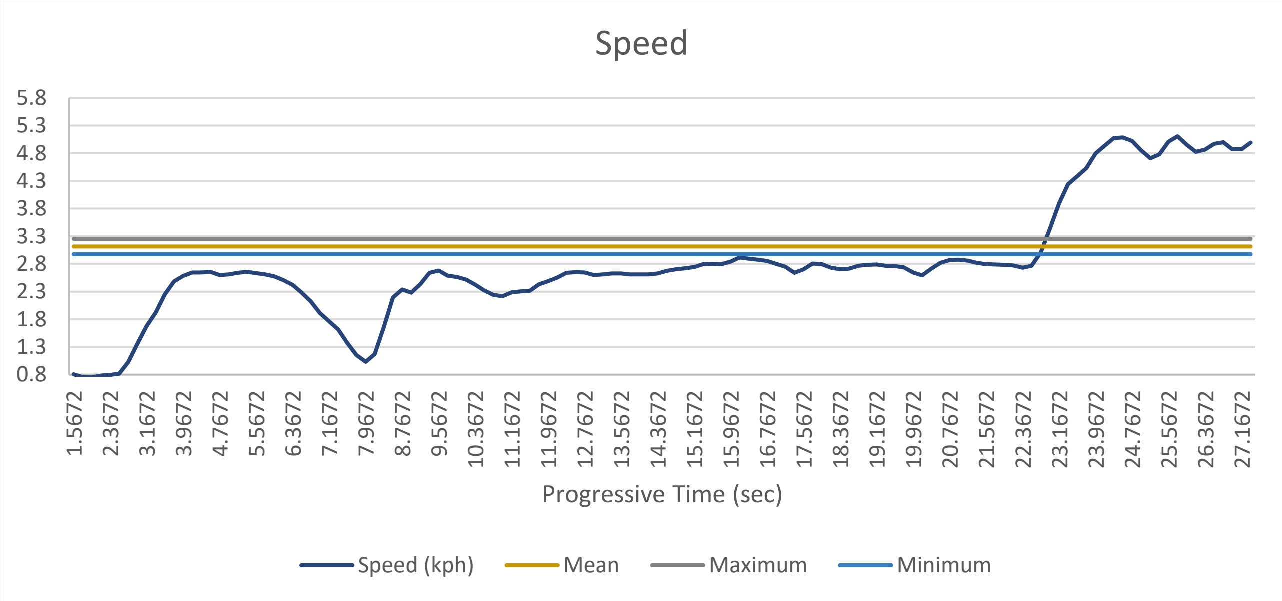
200mm – 3kph

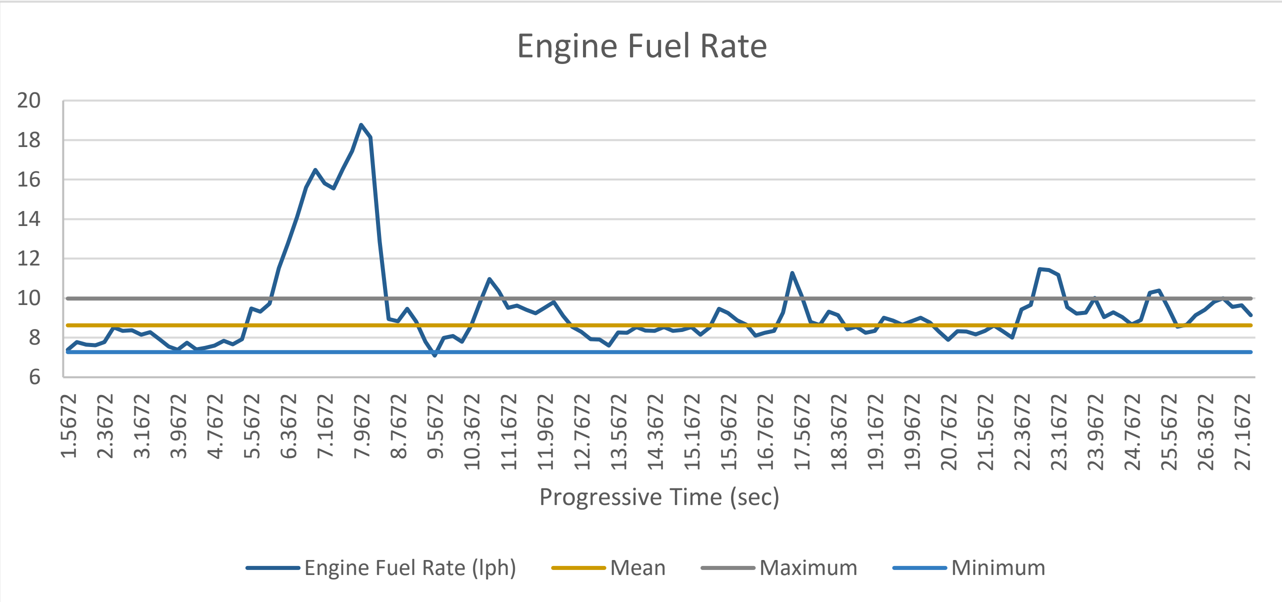


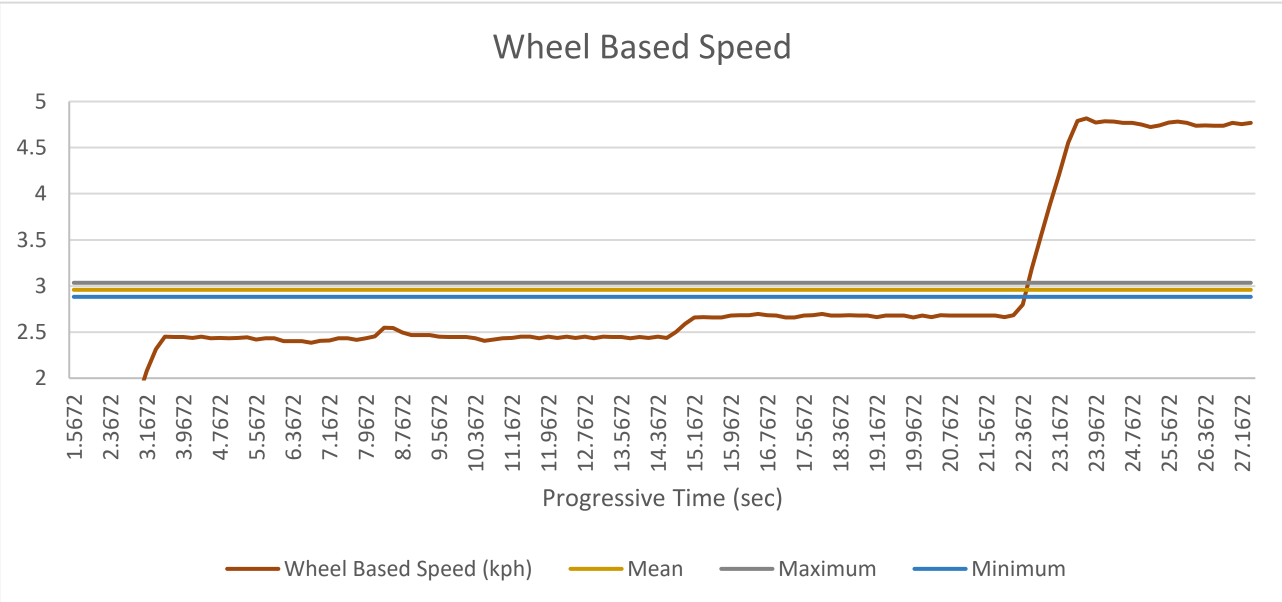
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1960
1940
1920
1900
1880
1860
1840
Engine RPM
1.5672
2.3672
3.1672
3.9672
4.7672
5.5672
6.3672
7.1672
7.9672
8.7672
9.5672
10.3672
11.1672
11.9672
12.7672
13.5672
14.3672
15.1672
15.9672
16.7672
17.5672
18.3672
19.1672
19.9672
20.7672
21.5672
22.3672
23.1672
23.9672
24.7672
25.5672
26.3672
27.1672
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

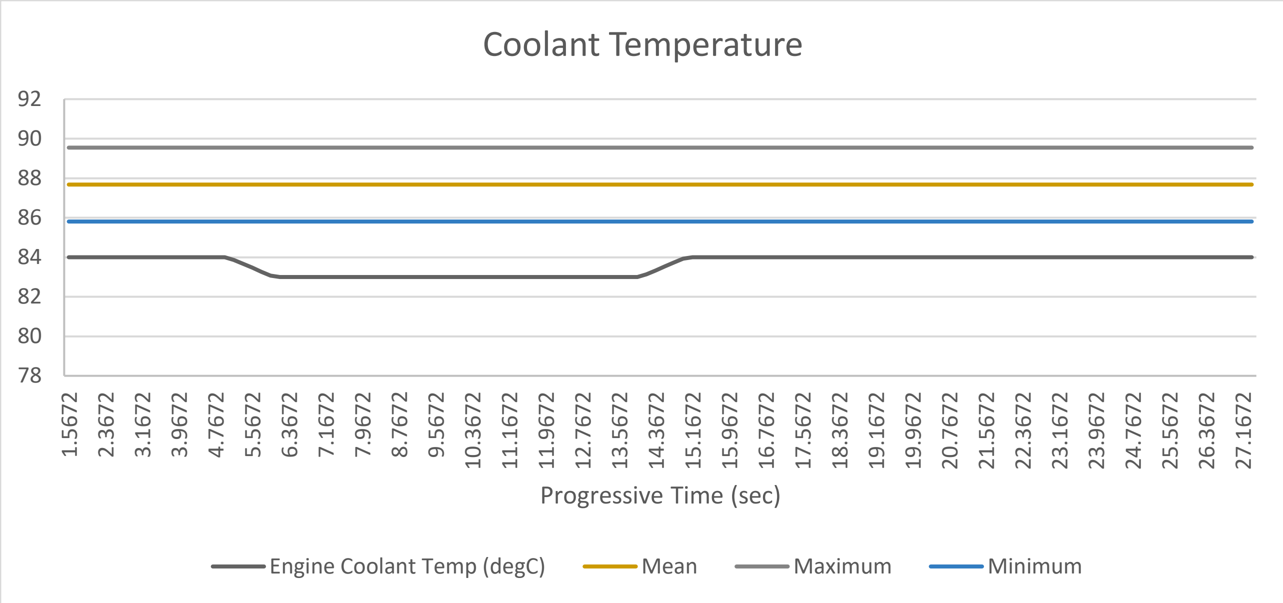


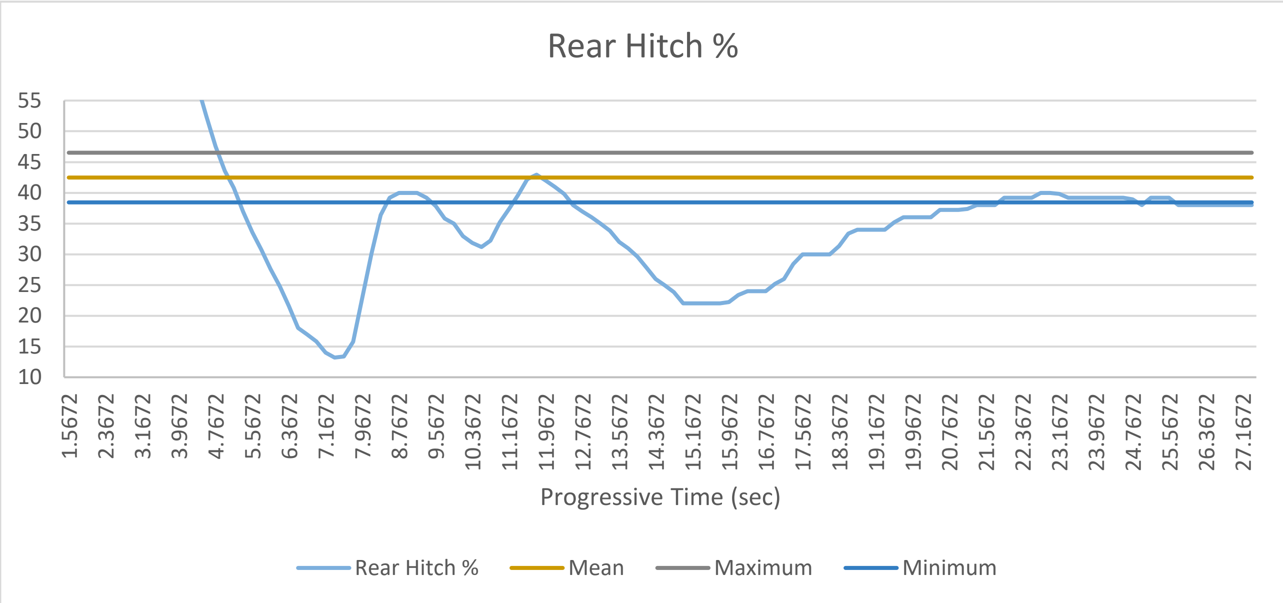
Engine Load
85
75
65
55
45
35
25
1.5672
2.3672
3.1672
3.9672
4.7672
5.5672
6.3672
7.1672
7.9672
8.7672
9.5672
10.3672
11.1672
11.9672
12.7672
13.5672
14.3672
15.1672
15.9672
16.7672
17.5672
18.3672
19.1672
19.9672
20.7672
21.5672
22.3672
23.1672
23.9672
24.7672
25.5672
26.3672
27.1672
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

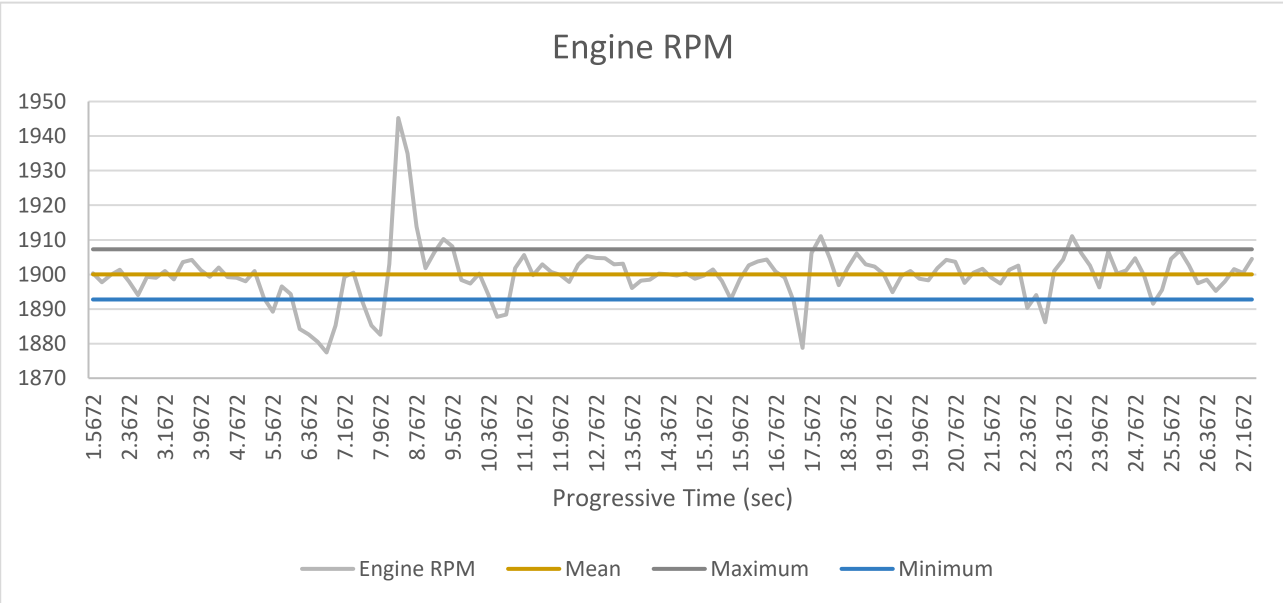

Speed
5.8
5.3
4.8
4.3
3.8
3.3
2.8
2.3
1.8
1.3
0.8
1.5672
2.3672
3.1672
3.9672
4.7672
5.5672
6.3672
7.1672
7.9672
8.7672
9.5672
10.3672
11.1672
11.9672
12.7672
13.5672
14.3672
15.1672
15.9672
16.7672
17.5672
18.3672
19.1672
19.9672
20.7672
21.5672
22.3672
23.1672
23.9672
24.7672
25.5672
26.3672
27.1672
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
20
18
16
14
12
10
8
6
1.5672
2.3672
3.1672
3.9672
4.7672
5.5672
6.3672
7.1672
7.9672
8.7672
9.5672
10.3672
11.1672
11.9672
12.7672
13.5672
14.3672
15.1672
15.9672
16.7672
17.5672
18.3672
19.1672
19.9672
20.7672
21.5672
22.3672
23.1672
23.9672
24.7672
25.5672
26.3672
27.1672
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

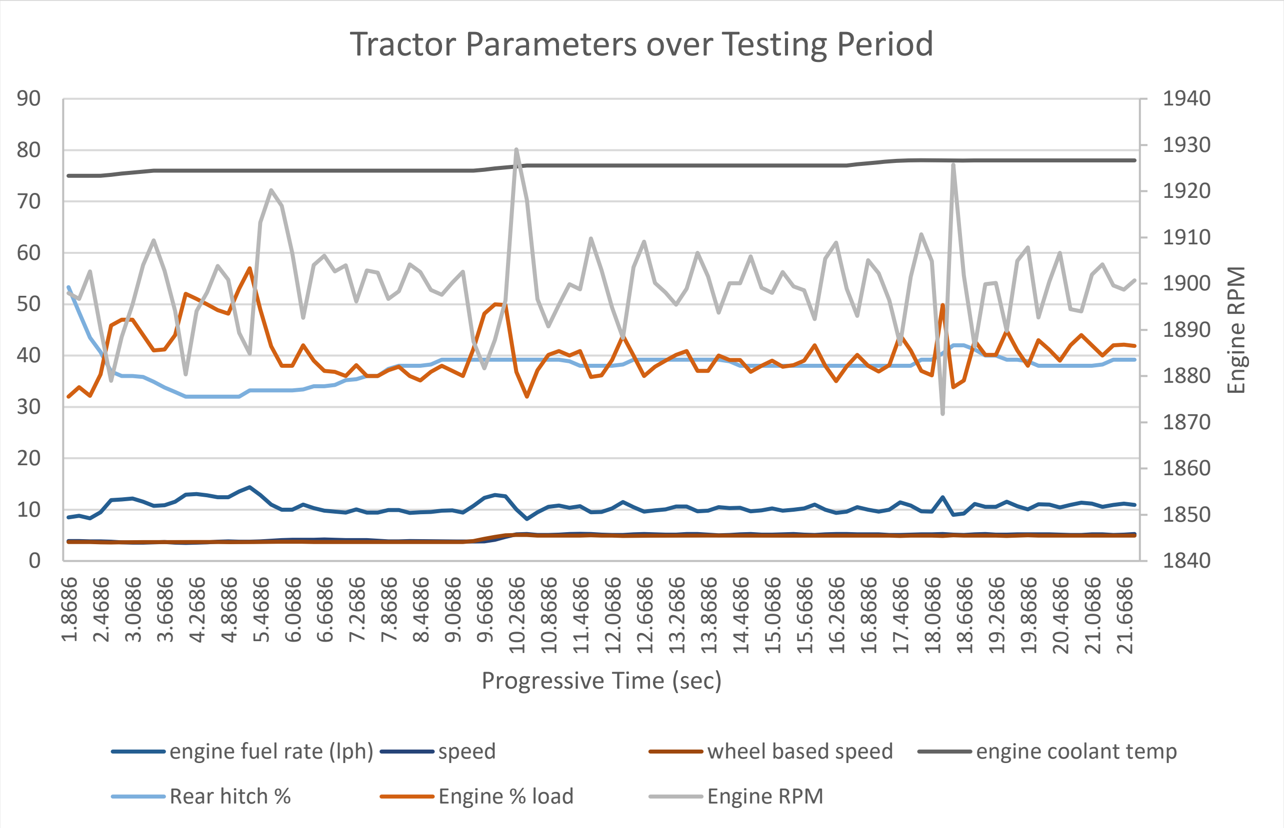

Wheel Based Speed
5
4.5
4
3.5
3
2.5
2
1.5672
2.3672
3.1672
3.9672
4.7672
5.5672
6.3672
7.1672
7.9672
8.7672
9.5672
10.3672
11.1672
11.9672
12.7672
13.5672
14.3672
15.1672
15.9672
16.7672
17.5672
18.3672
19.1672
19.9672
20.7672
21.5672
22.3672
23.1672
23.9672
24.7672
25.5672
26.3672
27.1672
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
92
90
88
86
84
82
80
78
1.5672 2.3672 3.1672 3.9672 4.7672 5.5672 6.3672 7.1672 7.9672 8.7672 9.5672 10.3672 11.1672 11.9672 12.7672 13.5672 14.3672 15.1672 15.9672 16.7672 17.5672 18.3672 19.1672 19.9672 20.7672 21.5672 22.3672 23.1672 23.9672 24.7672 25.5672 26.3672 27.1672
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

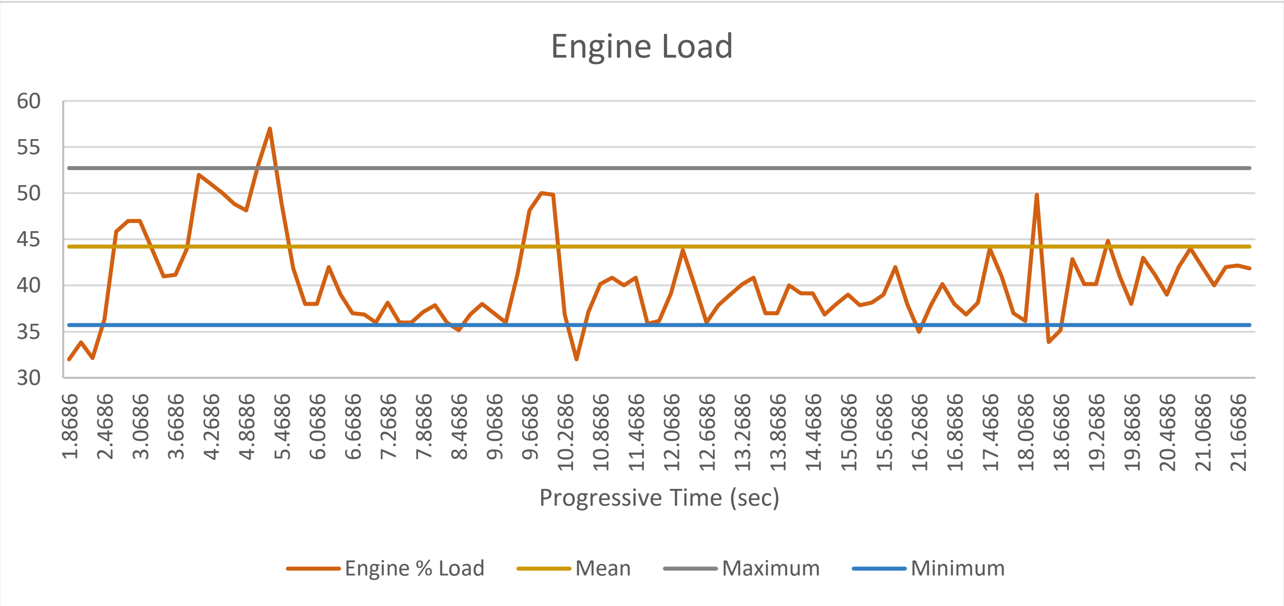

Rear Hitch %
55
50
45
40
35
30
25
20
15
10
1.5672 2.3672 3.1672 3.9672 4.7672 5.5672 6.3672 7.1672 7.9672 8.7672 9.5672 10.3672 11.1672 11.9672 12.7672 13.5672 14.3672 15.1672 15.9672 16.7672 17.5672 18.3672 19.1672 19.9672 20.7672 21.5672 22.3672 23.1672 23.9672 24.7672 25.5672 26.3672 27.1672
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1950
1940
1930
1920
1910
1900
1890
1880
1870
1.5672 2.3672 3.1672 3.9672 4.7672 5.5672 6.3672 7.1672 7.9672 8.7672 9.5672 10.3672 11.1672 11.9672 12.7672 13.5672 14.3672 15.1672 15.9672 16.7672 17.5672 18.3672 19.1672 19.9672 20.7672 21.5672 22.3672 23.1672 23.9672 24.7672 25.5672 26.3672 27.1672
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

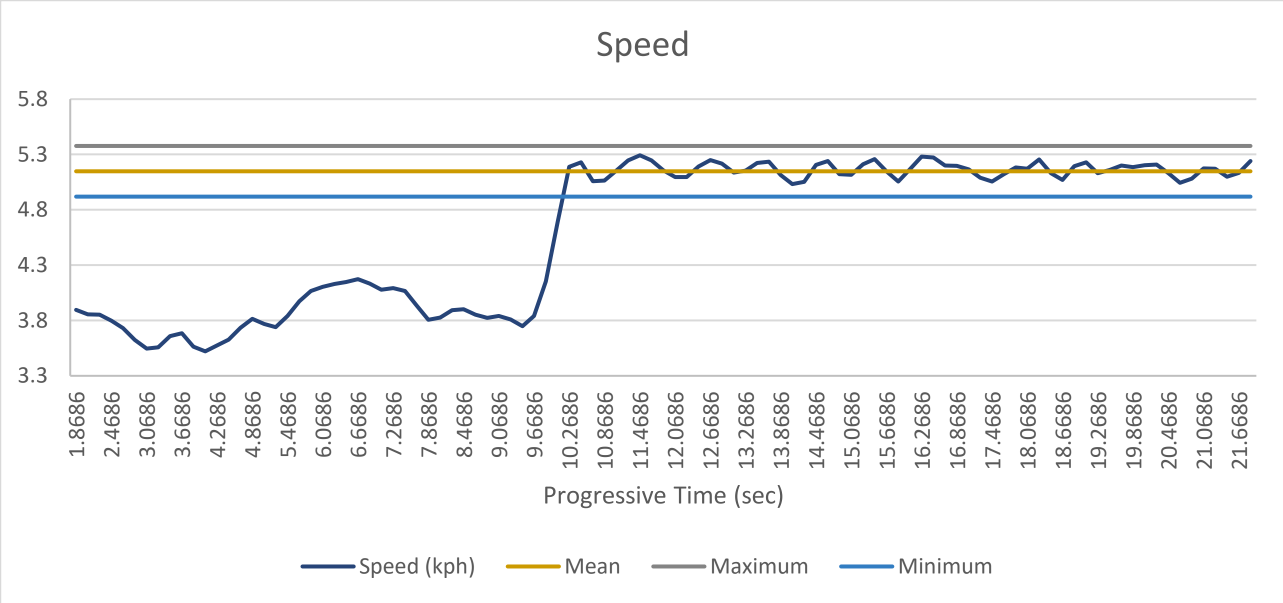
200mm – 5kph

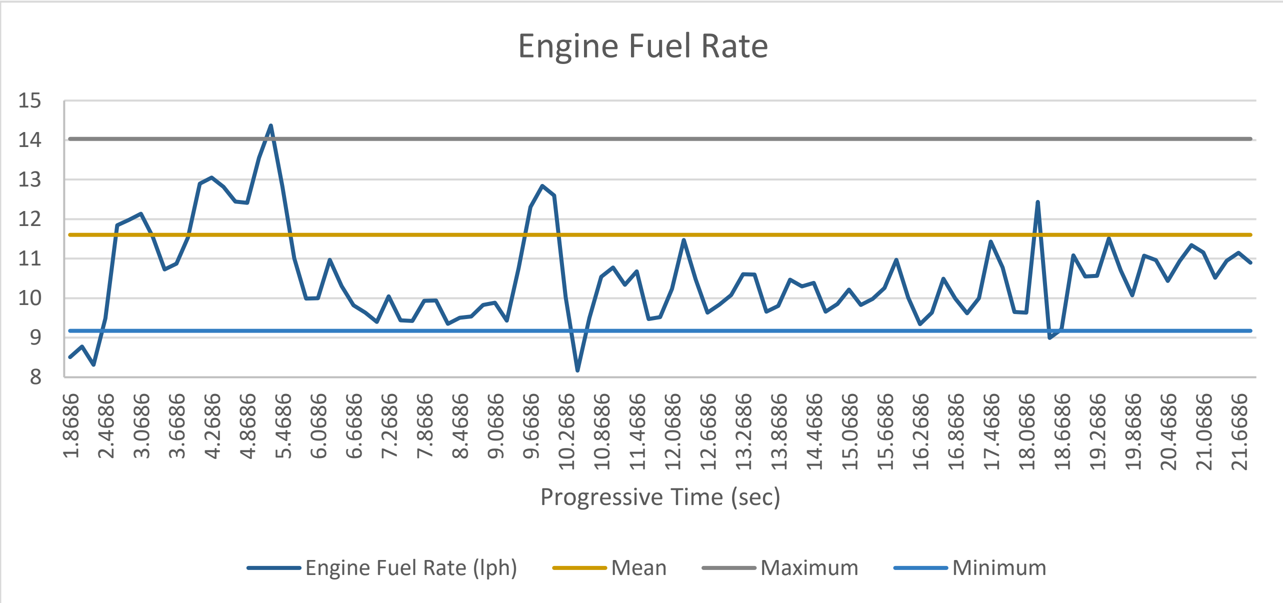


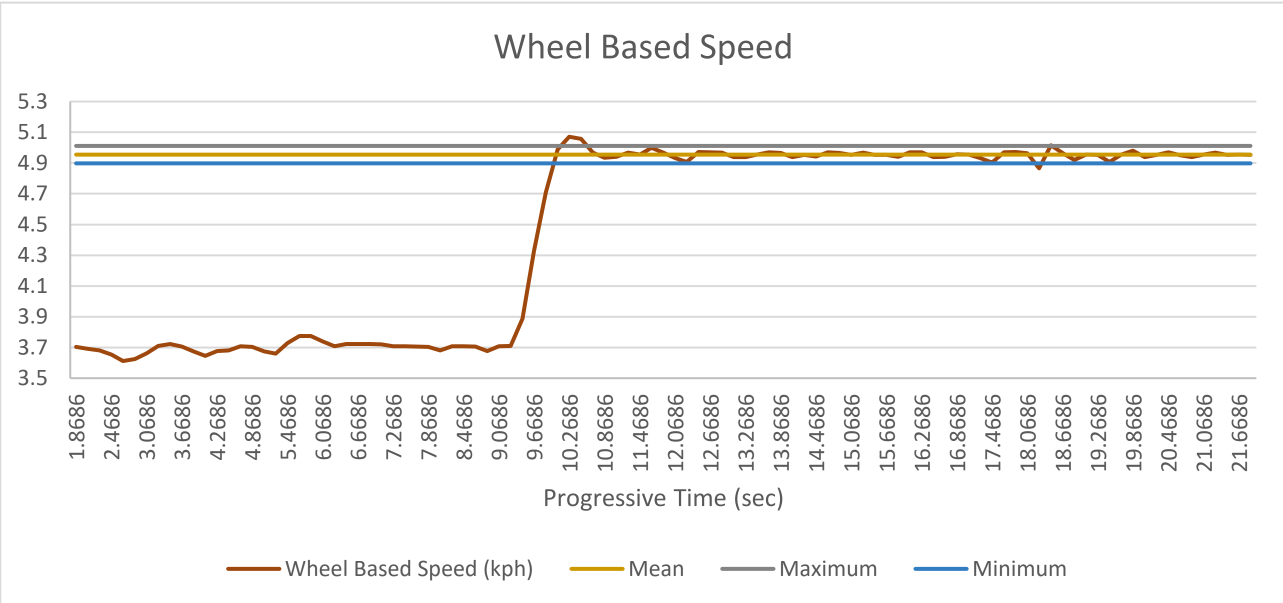
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
Engine RPM
1.8686
2.4686
3.0686
3.6686
4.2686
4.8686
5.4686
6.0686
6.6686
7.2686
7.8686
8.4686
9.0686
9.6686
10.2686
10.8686
11.4686
12.0686
12.6686
13.2686
13.8686
14.4686
15.0686
15.6686
16.2686
16.8686
17.4686
18.0686
18.6686
19.2686
19.8686
20.4686
21.0686
21.6686
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

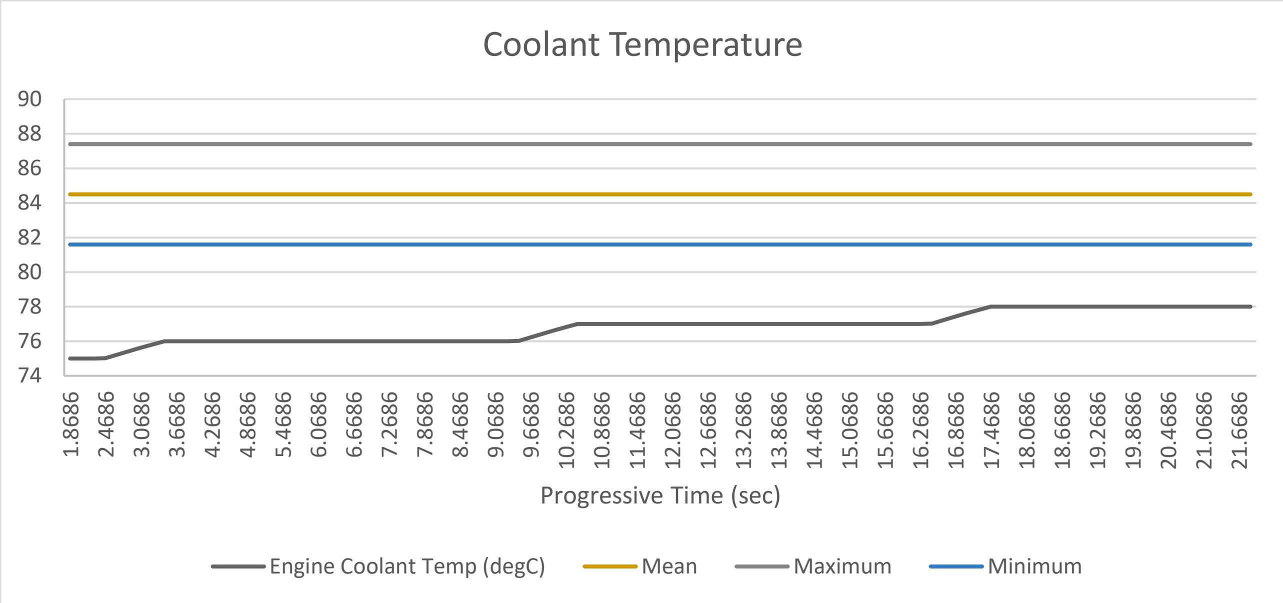


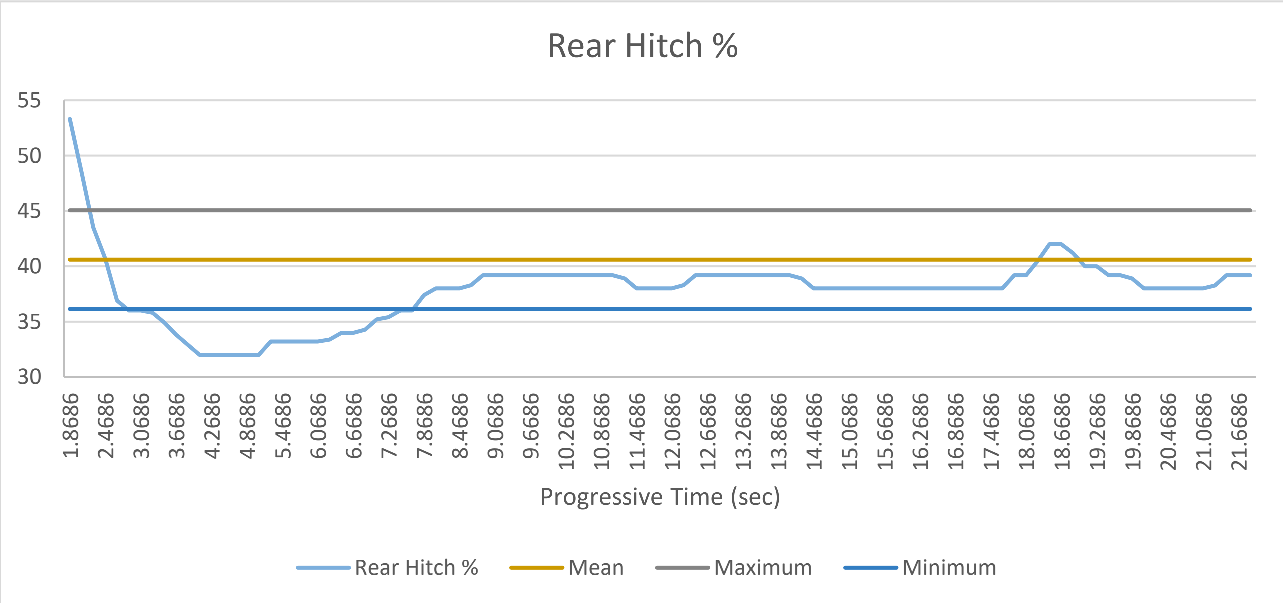
Engine Load
60
55
50
45
40
35
30
1.8686
2.4686
3.0686
3.6686
4.2686
4.8686
5.4686
6.0686
6.6686
7.2686
7.8686
8.4686
9.0686
9.6686
10.2686
10.8686
11.4686
12.0686
12.6686
13.2686
13.8686
14.4686
15.0686
15.6686
16.2686
16.8686
17.4686
18.0686
18.6686
19.2686
19.8686
20.4686
21.0686
21.6686
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

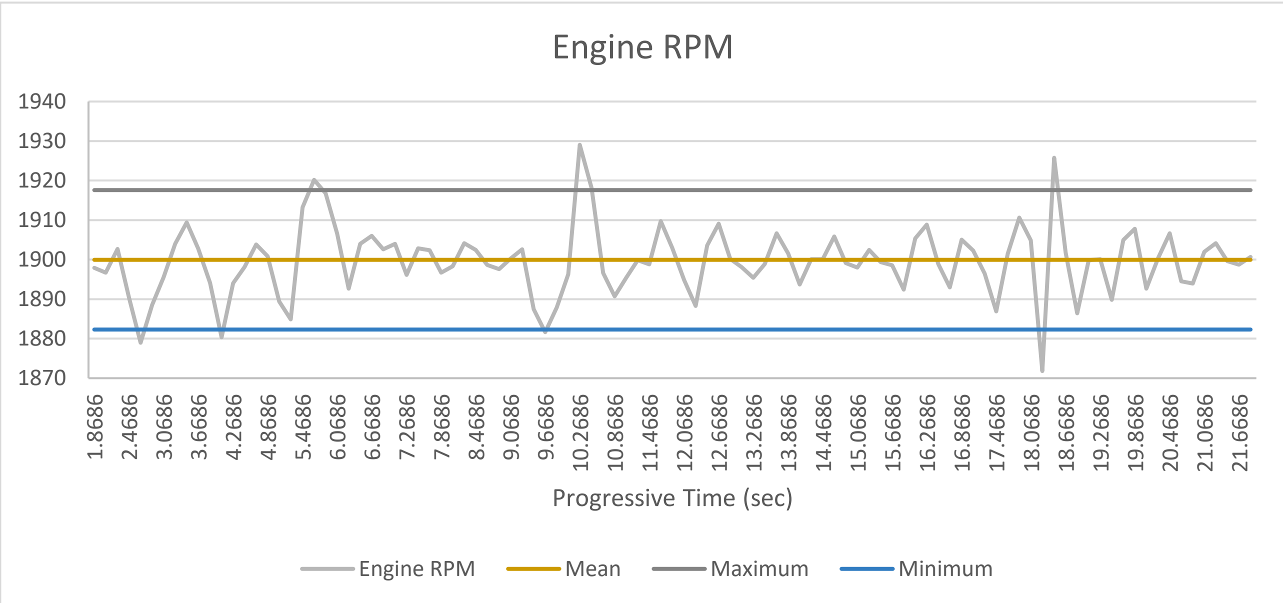

Speed
5.8
5.3
4.8
4.3
3.8
3.3
1.8686 2.4686 3.0686 3.6686 4.2686 4.8686 5.4686 6.0686 6.6686 7.2686 7.8686 8.4686 9.0686 9.6686 10.2686 10.8686 11.4686 12.0686 12.6686 13.2686 13.8686 14.4686 15.0686 15.6686 16.2686 16.8686 17.4686 18.0686 18.6686 19.2686 19.8686 20.4686 21.0686 21.6686
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
15
14
13
12
11
10
9
8
1.8686 2.4686 3.0686 3.6686 4.2686 4.8686 5.4686 6.0686 6.6686 7.2686 7.8686 8.4686 9.0686 9.6686 10.2686 10.8686 11.4686 12.0686 12.6686 13.2686 13.8686 14.4686 15.0686 15.6686 16.2686 16.8686 17.4686 18.0686 18.6686 19.2686 19.8686 20.4686 21.0686 21.6686
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
5.3
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
1.8686 2.4686 3.0686 3.6686 4.2686 4.8686 5.4686 6.0686 6.6686 7.2686 7.8686 8.4686 9.0686 9.6686 10.2686 10.8686 11.4686 12.0686 12.6686 13.2686 13.8686 14.4686 15.0686 15.6686 16.2686 16.8686 17.4686 18.0686 18.6686 19.2686 19.8686 20.4686 21.0686 21.6686
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

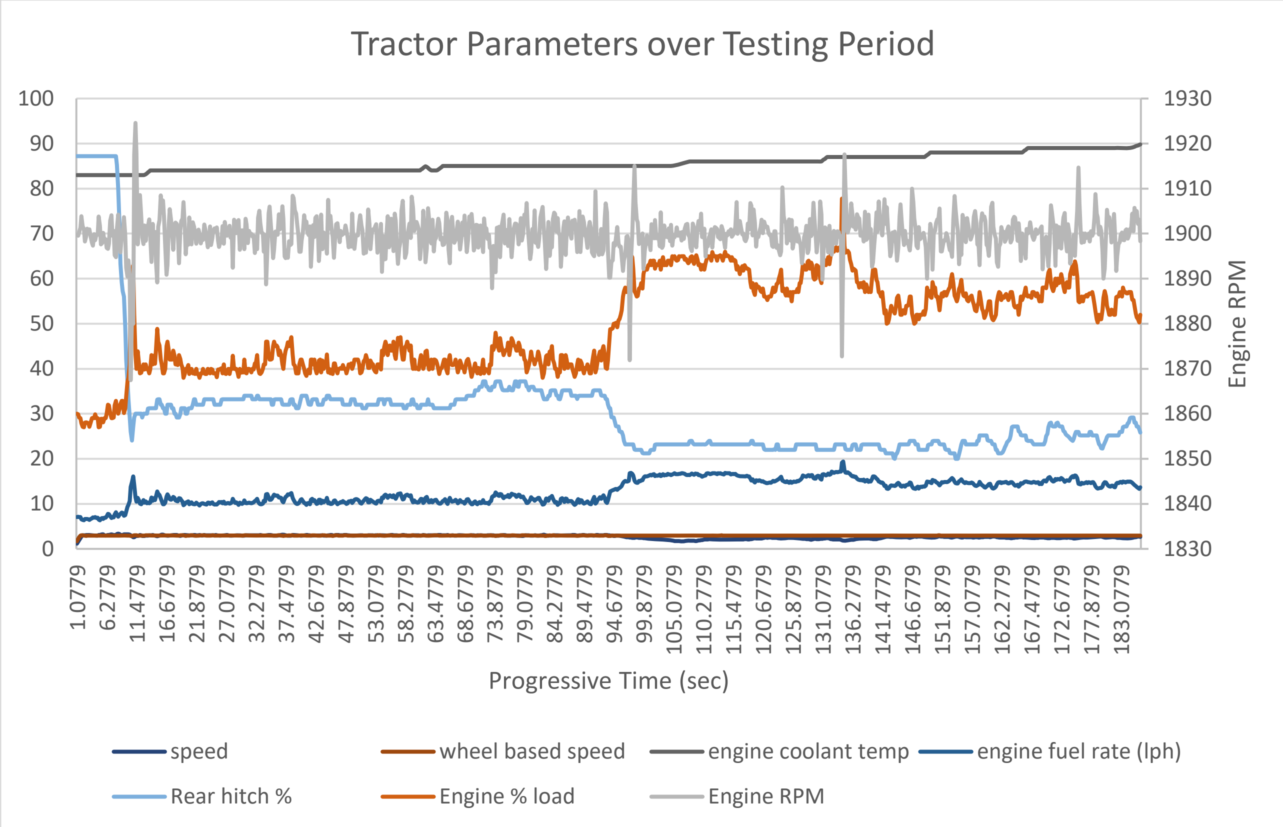

Coolant Temperature
90
88
86
84
82
80
78
76
74
1.8686
2.4686
3.0686
3.6686
4.2686
4.8686
5.4686
6.0686
6.6686
7.2686
7.8686
8.4686
9.0686
9.6686
10.2686
10.8686
11.4686
12.0686
12.6686
13.2686
13.8686
14.4686
15.0686
15.6686
16.2686
16.8686
17.4686
18.0686
18.6686
19.2686
19.8686
20.4686
21.0686
21.6686
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

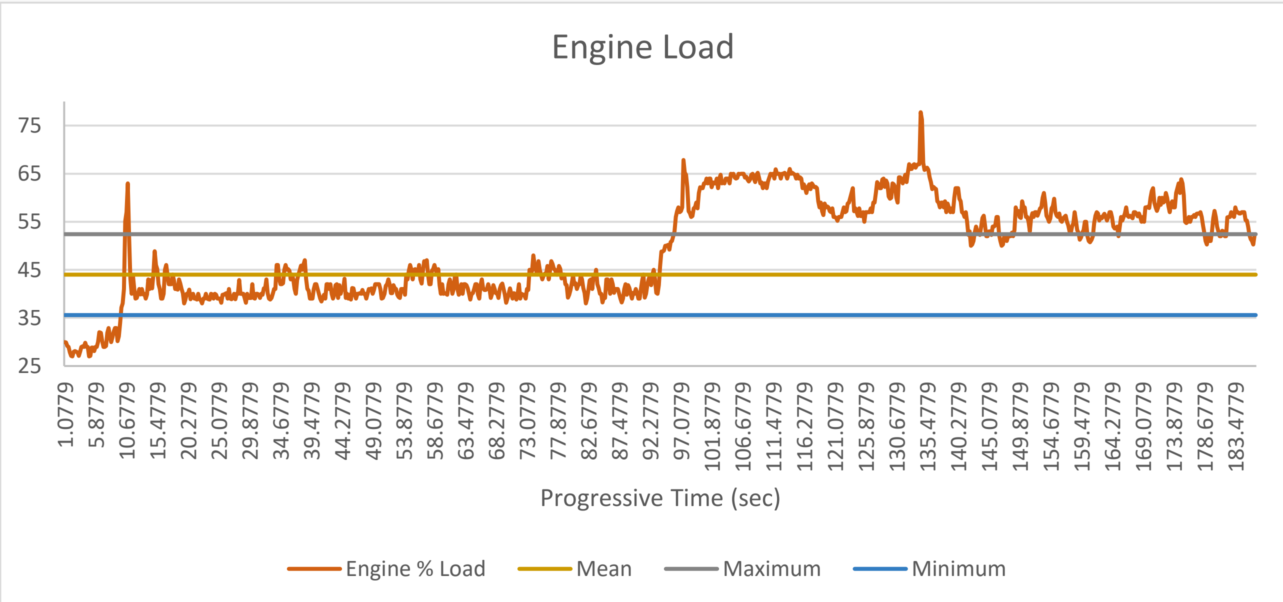

Rear Hitch %
55
50
45
40
35
30
1.8686
2.4686
3.0686
3.6686
4.2686
4.8686
5.4686
6.0686
6.6686
7.2686
7.8686
8.4686
9.0686
9.6686
10.2686
10.8686
11.4686
12.0686
12.6686
13.2686
13.8686
14.4686
15.0686
15.6686
16.2686
16.8686
17.4686
18.0686
18.6686
19.2686
19.8686
20.4686
21.0686
21.6686
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

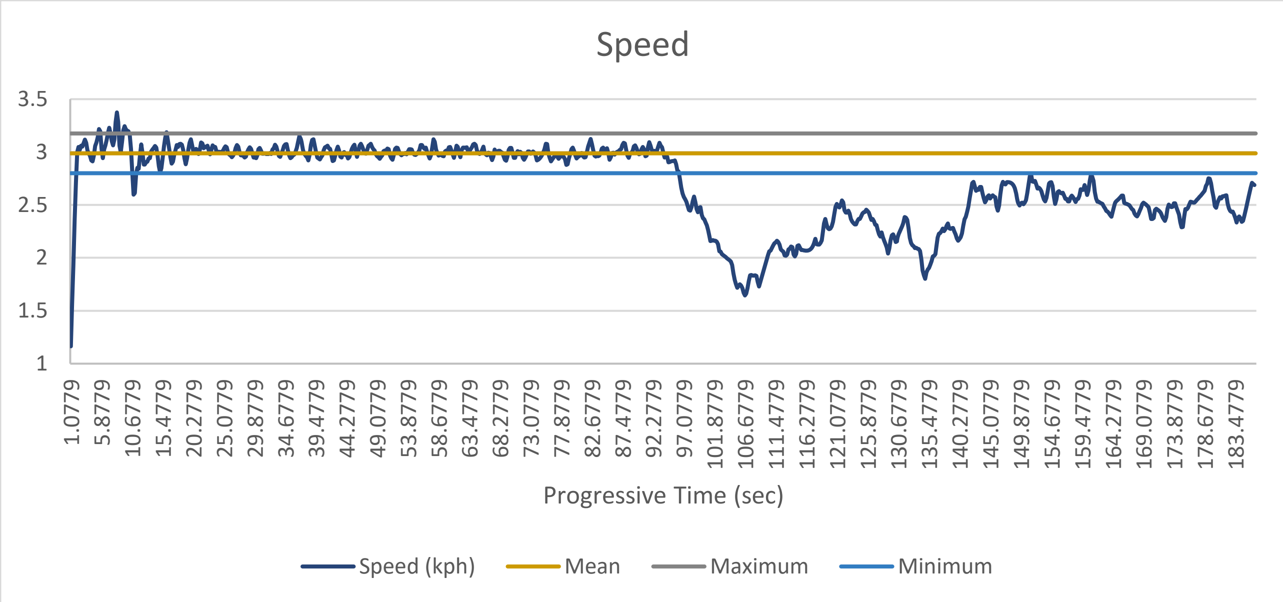

Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1.8686
2.4686
3.0686
3.6686
4.2686
4.8686
5.4686
6.0686
6.6686
7.2686
7.8686
8.4686
9.0686
9.6686
10.2686
10.8686
11.4686
12.0686
12.6686
13.2686
13.8686
14.4686
15.0686
15.6686
16.2686
16.8686
17.4686
18.0686
18.6686
19.2686
19.8686
20.4686
21.0686
21.6686
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

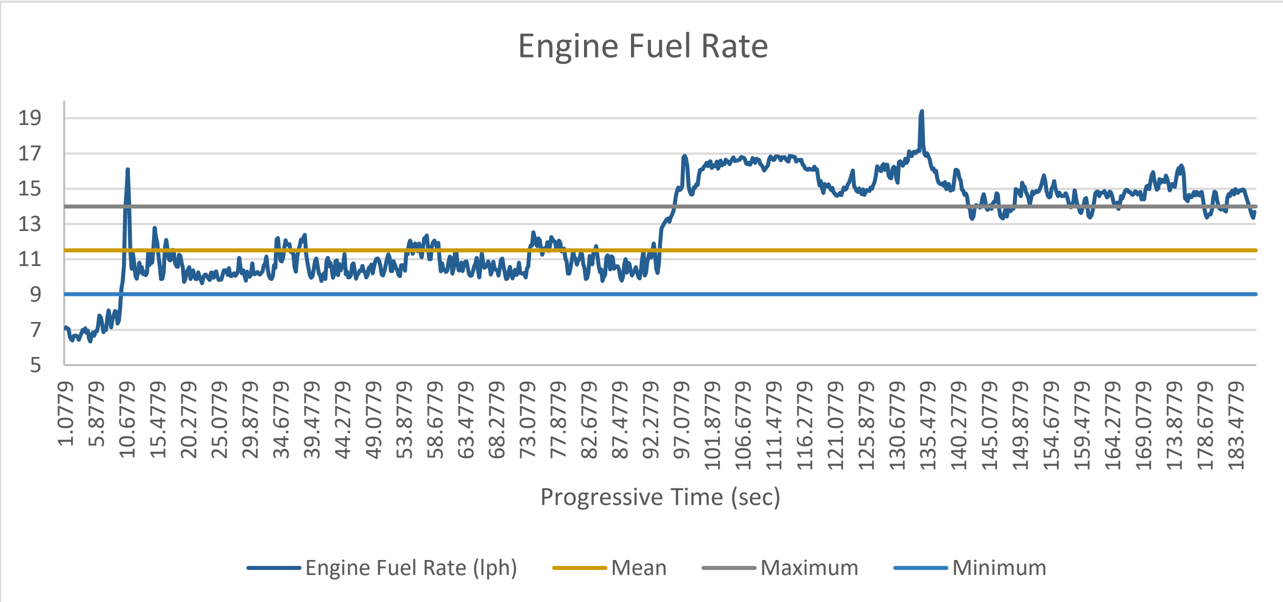
Appendix H – 3PL Deep Ripper – Ripper digging in too far data

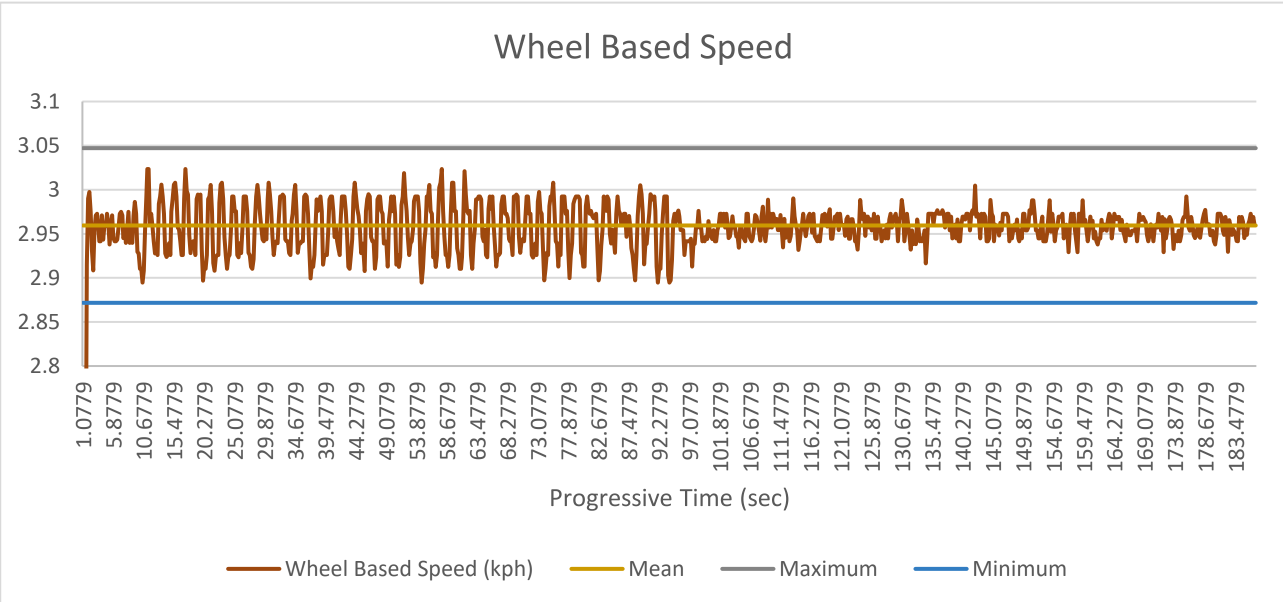
300mm – 3kph

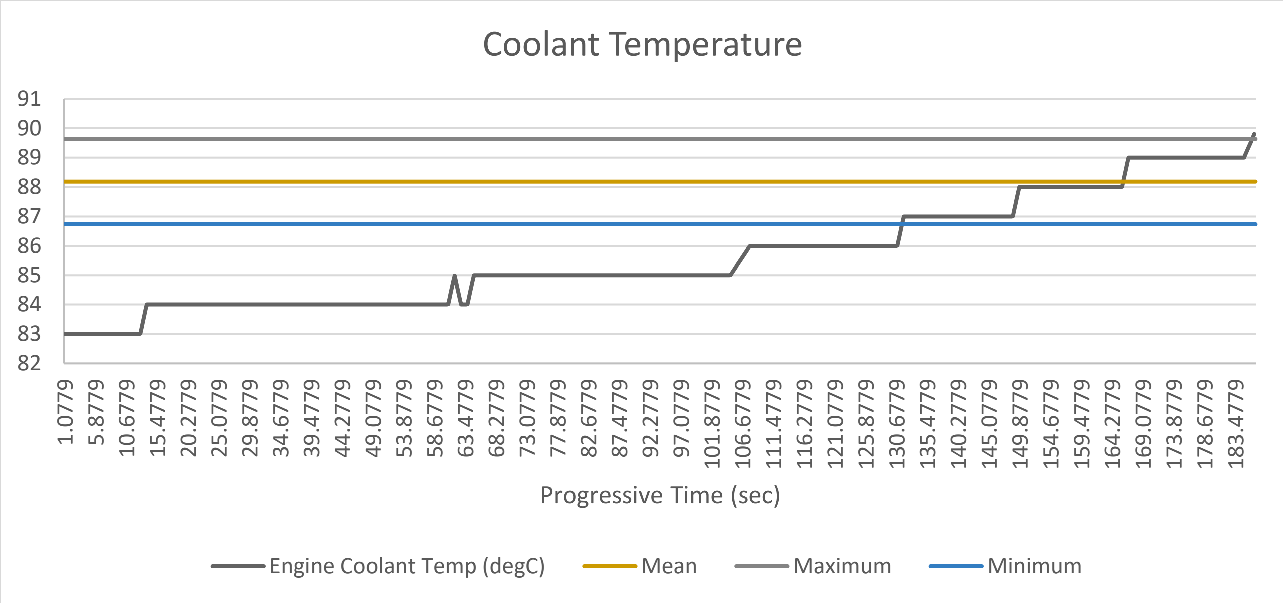


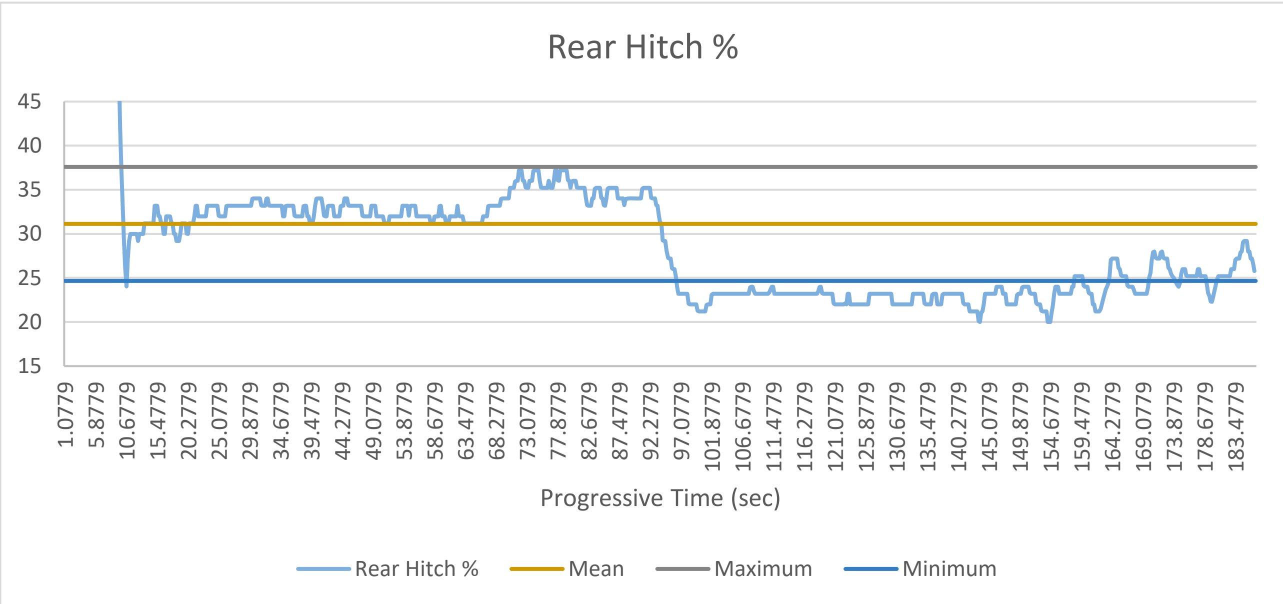


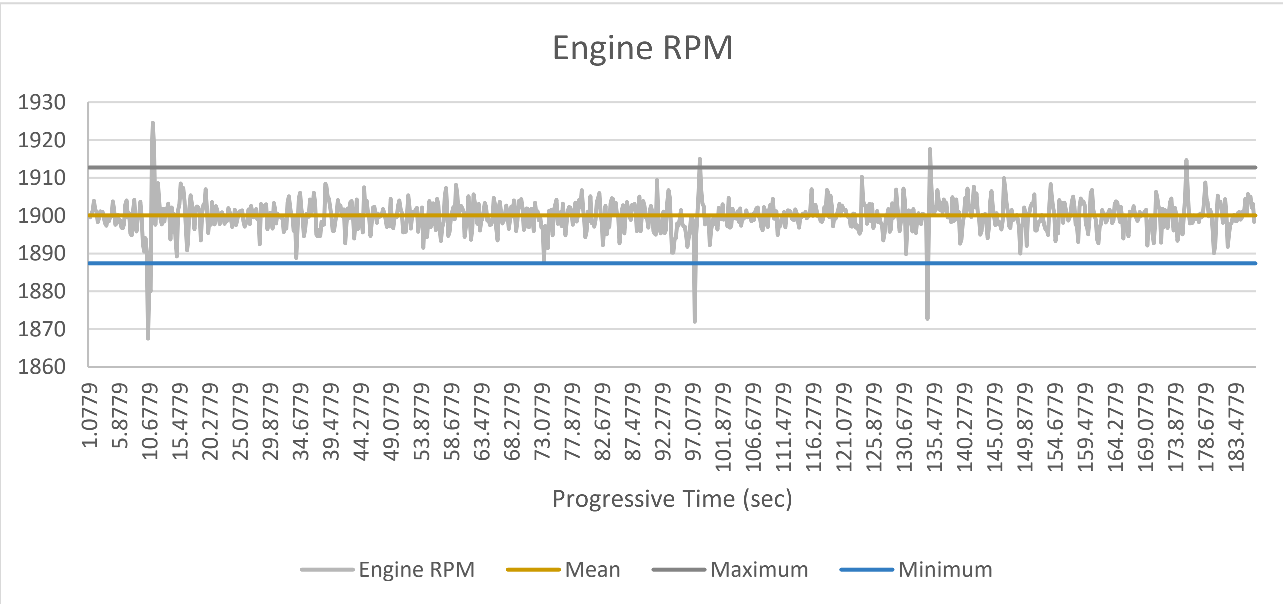

Speed
3.5
3
2.5
2
1.5
1
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
19
17
15
13
11
9
7
5
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

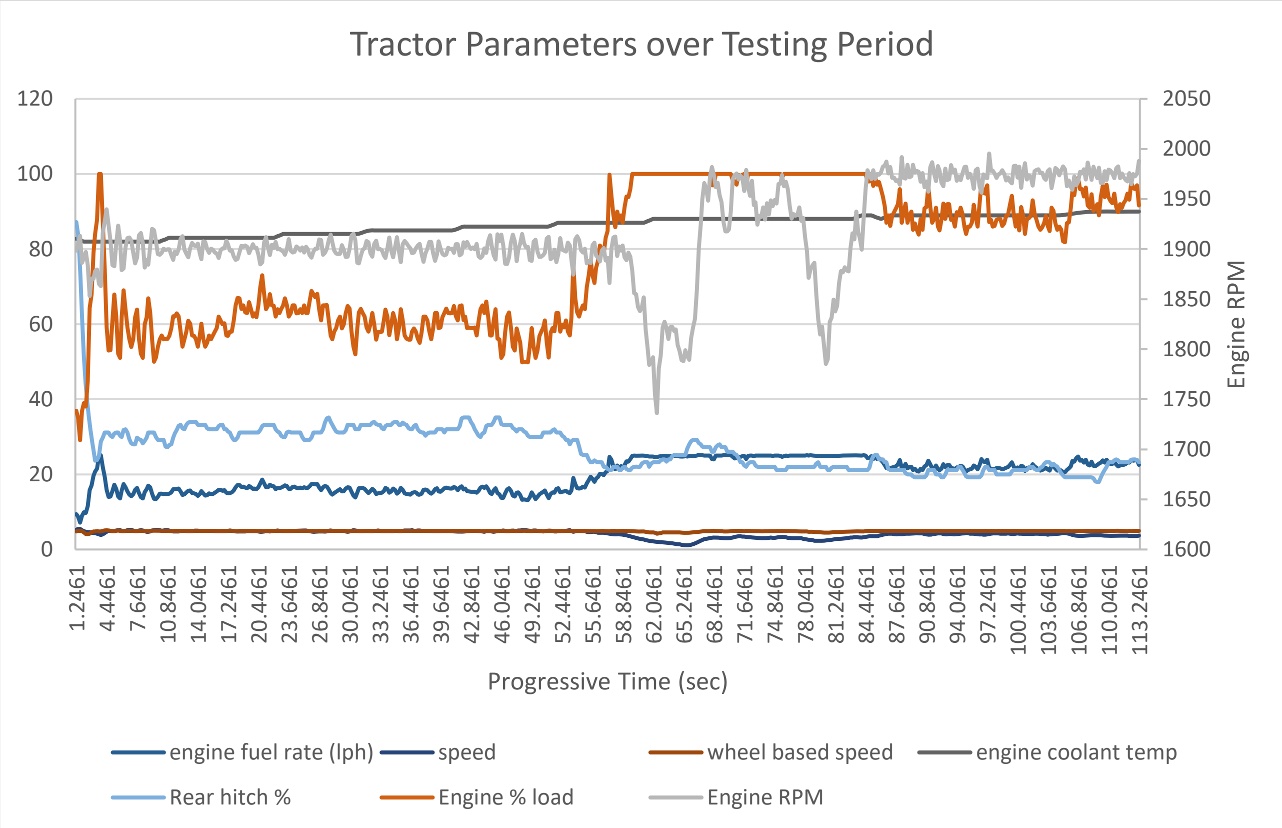

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

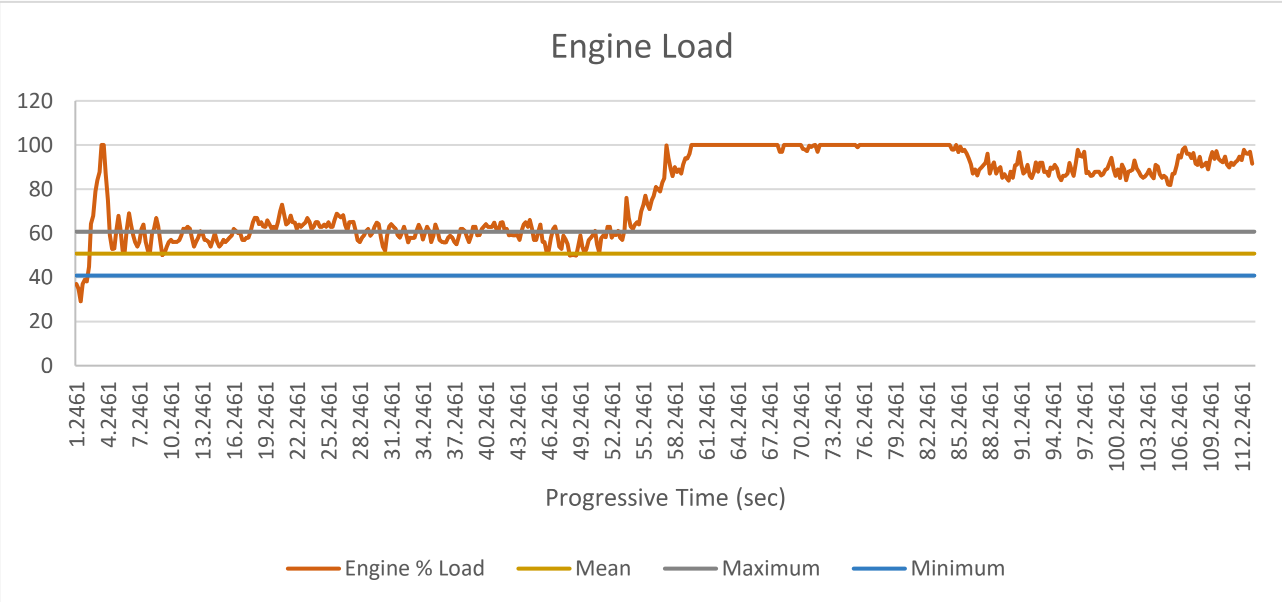

Coolant Temperature
91
90
89
88
87
86
85
84
83
82
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

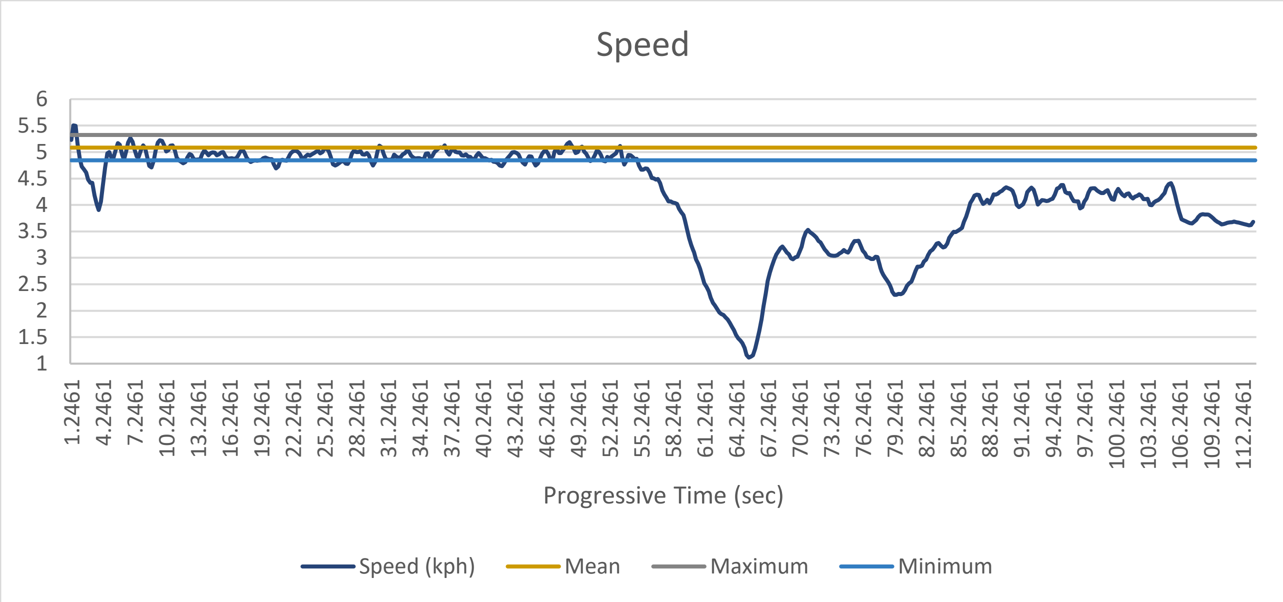

Rear Hitch %
45
40
35
30
25
20
15
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

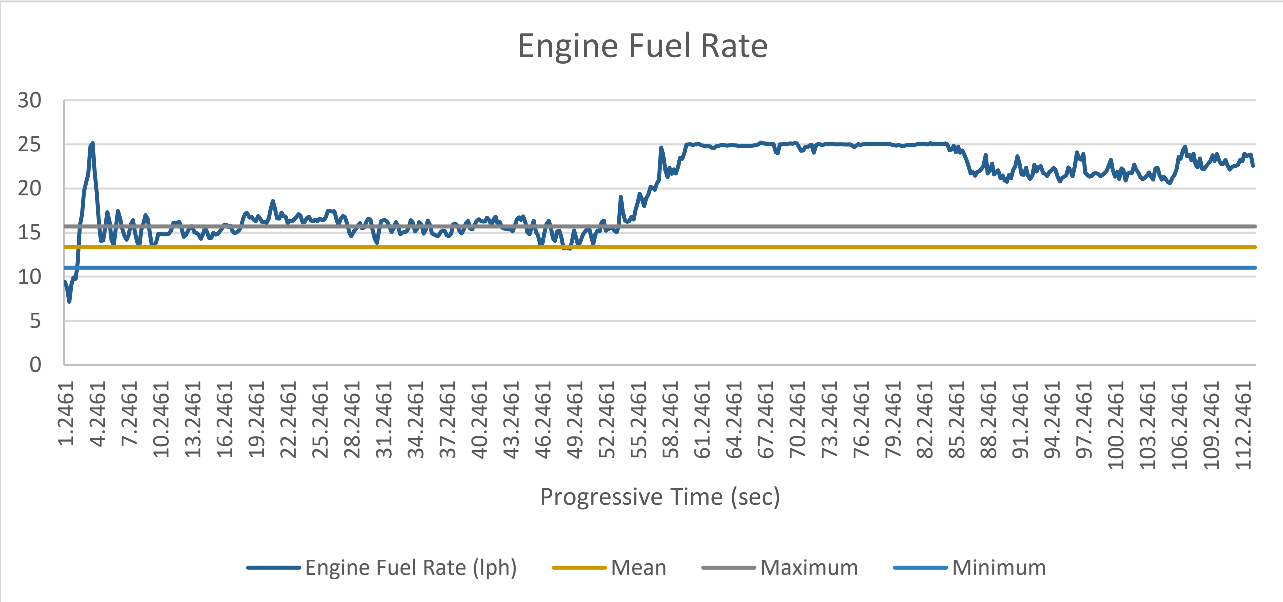

Engine RPM
1930
1920
1910
1900
1890
1880
1870
1860
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

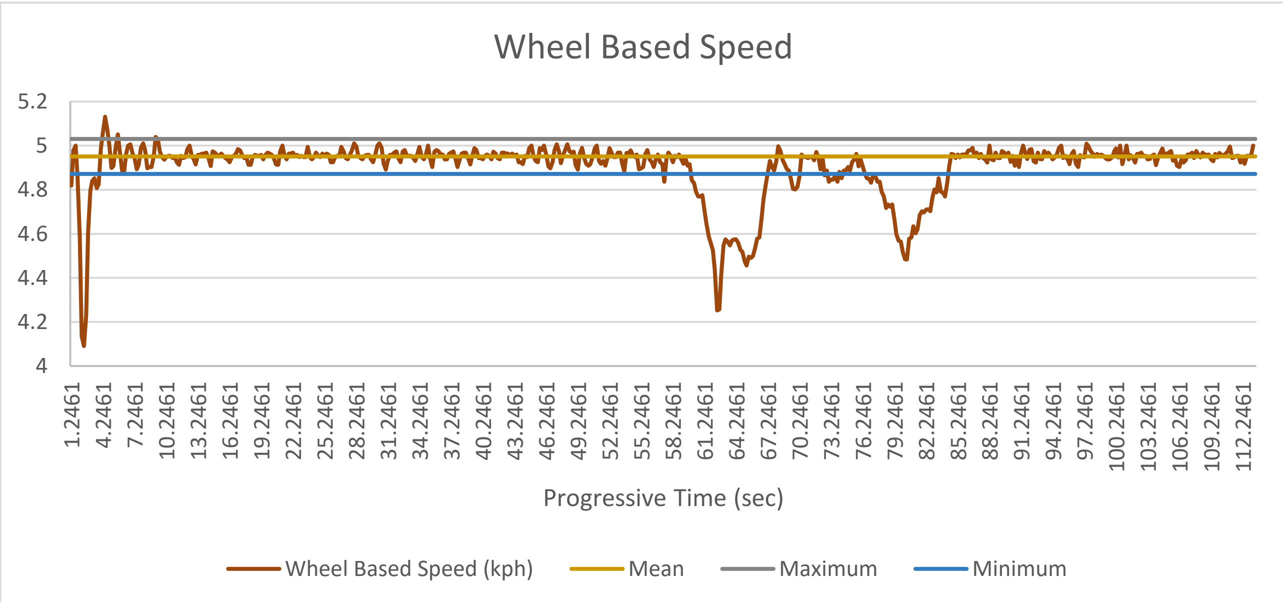
300mm – 5kph

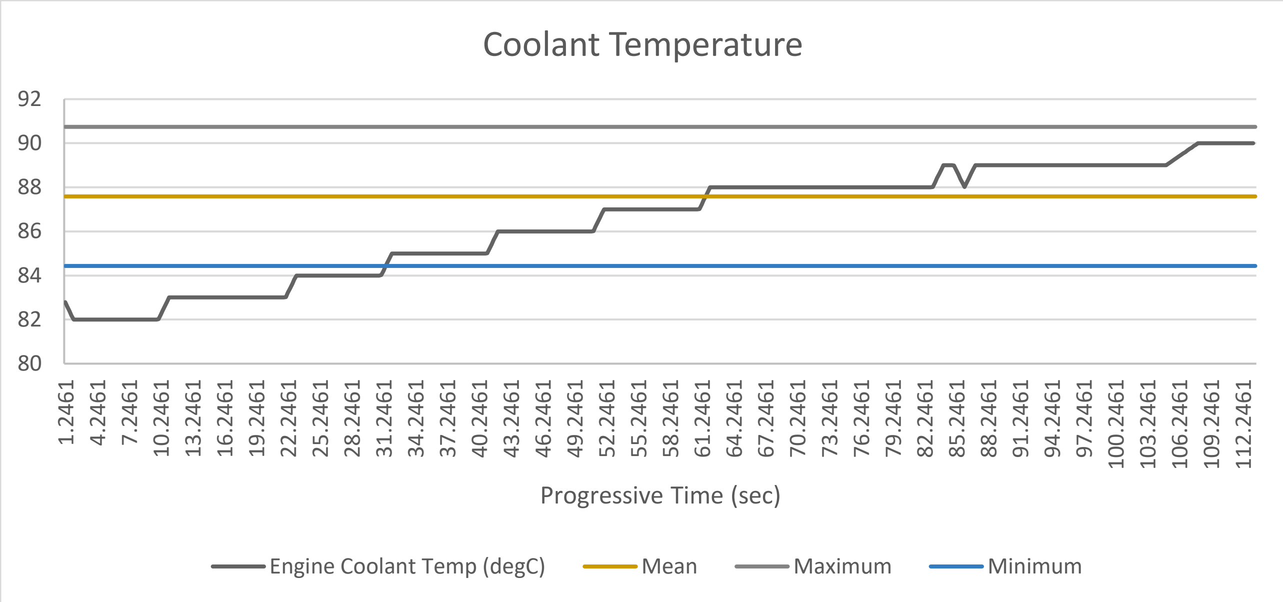

Tractor Parameters over Testing Period
120
100
80
60
40
20
0
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

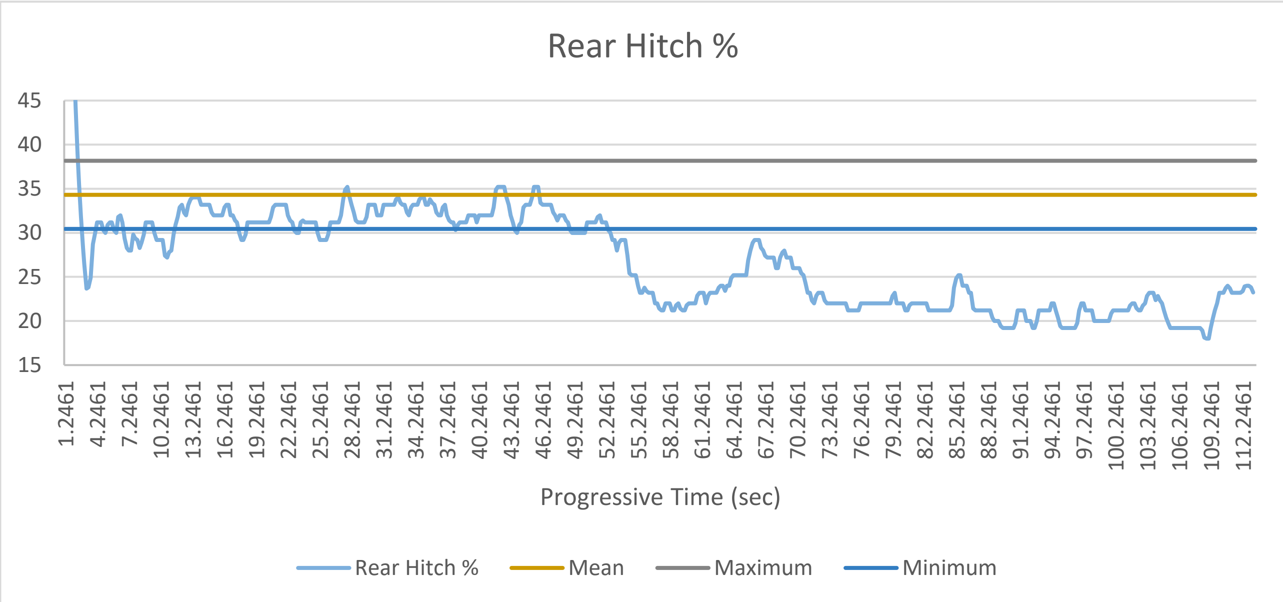

Engine Load
120
100
80
60
40
20
0
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

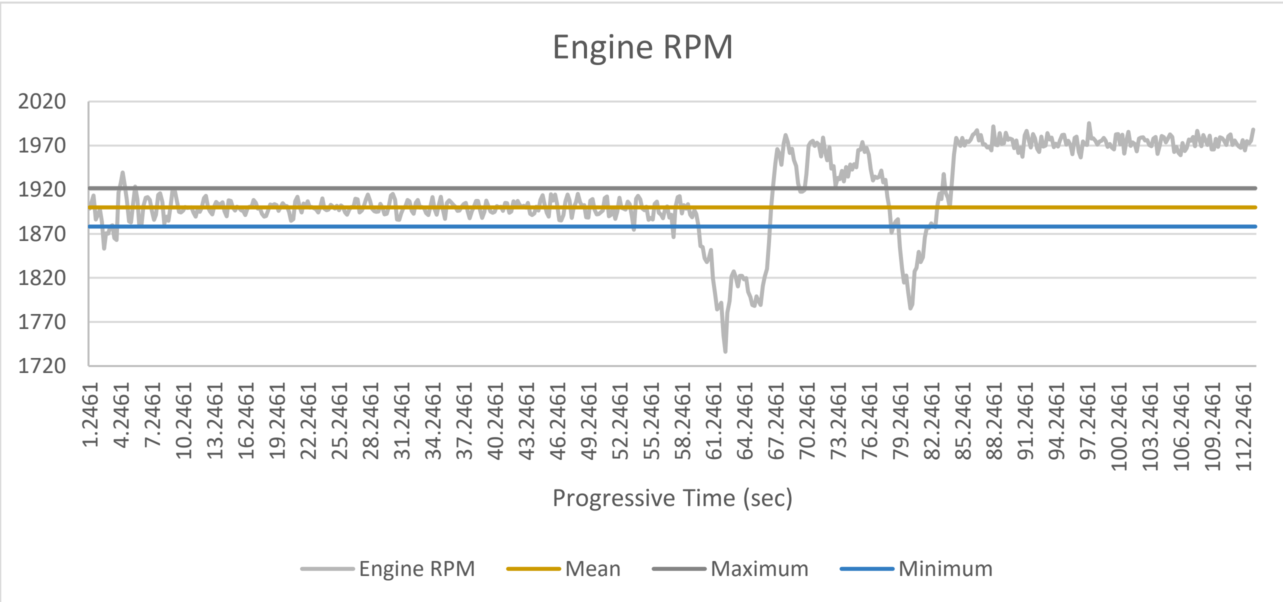

Speed
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
1.2461
4.2461
7.2461
10.2461
13.2461
16.2461
19.2461
22.2461
25.2461
28.2461
31.2461
34.2461
37.2461
40.2461
43.2461
46.2461
49.2461
52.2461
55.2461
58.2461
61.2461
64.2461
67.2461
70.2461
73.2461
76.2461
79.2461
82.2461
85.2461
88.2461
91.2461
94.2461
97.2461
100.2461
103.2461
106.2461
109.2461
112.2461
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
30
25
20
15
10
5
0
1.2461
4.2461
7.2461
10.2461
13.2461
16.2461
19.2461
22.2461
25.2461
28.2461
31.2461
34.2461
37.2461
40.2461
43.2461
46.2461
49.2461
52.2461
55.2461
58.2461
61.2461
64.2461
67.2461
70.2461
73.2461
76.2461
79.2461
82.2461
85.2461
88.2461
91.2461
94.2461
97.2461
100.2461
103.2461
106.2461
109.2461
112.2461
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

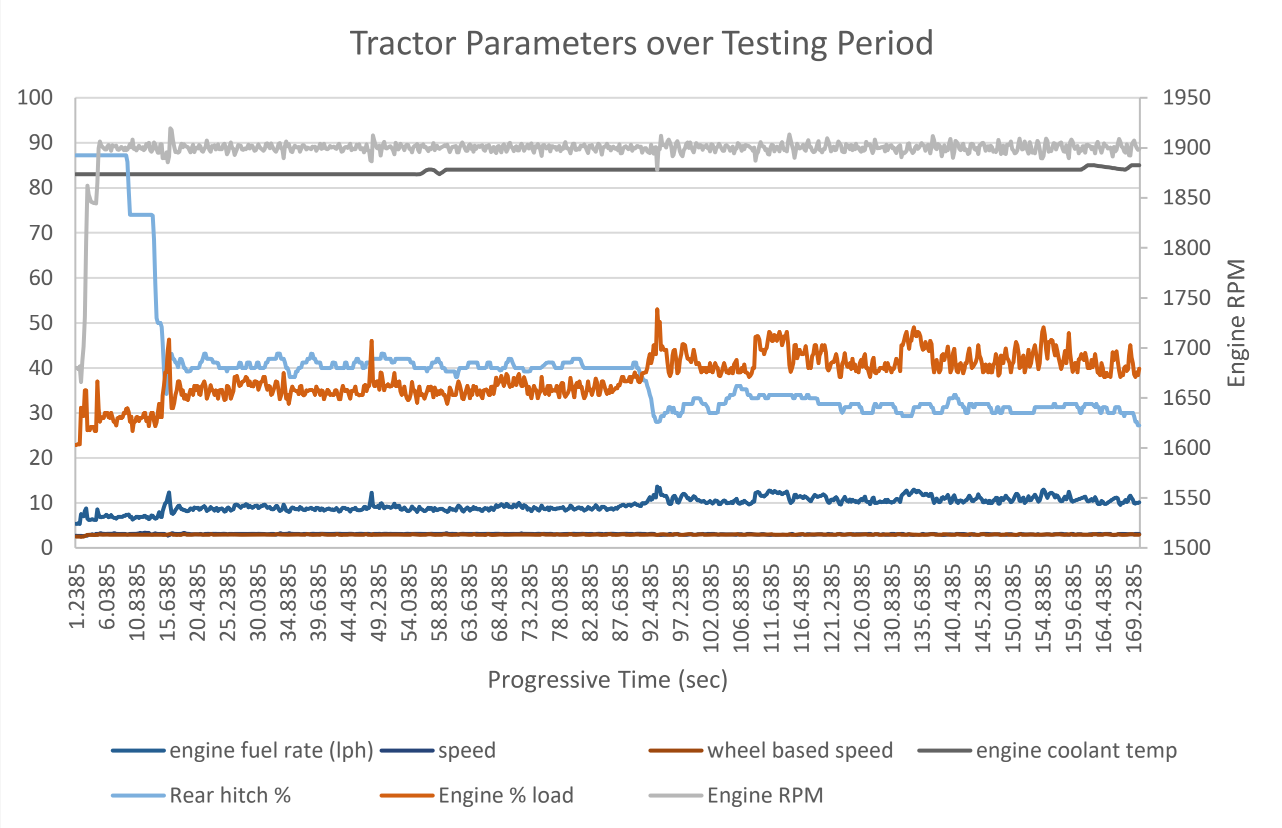

Wheel Based Speed
5.2
5
4.8
4.6
4.4
4.2
4
1.2461
4.2461
7.2461
10.2461
13.2461
16.2461
19.2461
22.2461
25.2461
28.2461
31.2461
34.2461
37.2461
40.2461
43.2461
46.2461
49.2461
52.2461
55.2461
58.2461
61.2461
64.2461
67.2461
70.2461
73.2461
76.2461
79.2461
82.2461
85.2461
88.2461
91.2461
94.2461
97.2461
100.2461
103.2461
106.2461
109.2461
112.2461
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
92
90
88
86
84
82
80
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

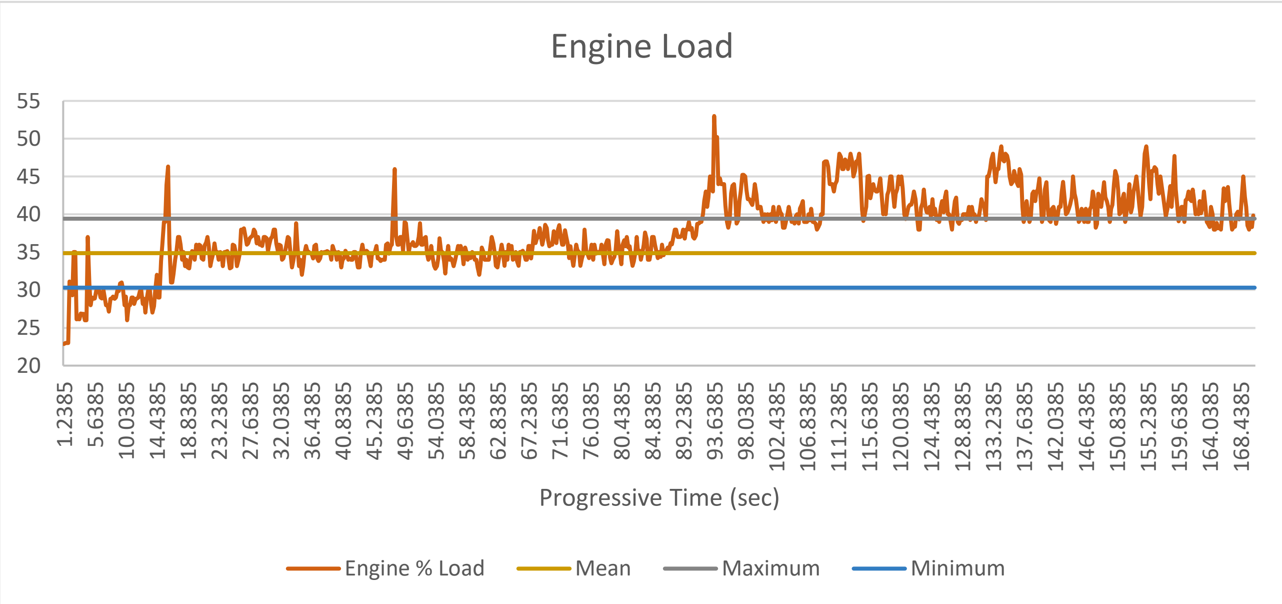

Rear Hitch %
45
40
35
30
25
20
15
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
2020
1970
1920
1870
1820
1770
1720
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

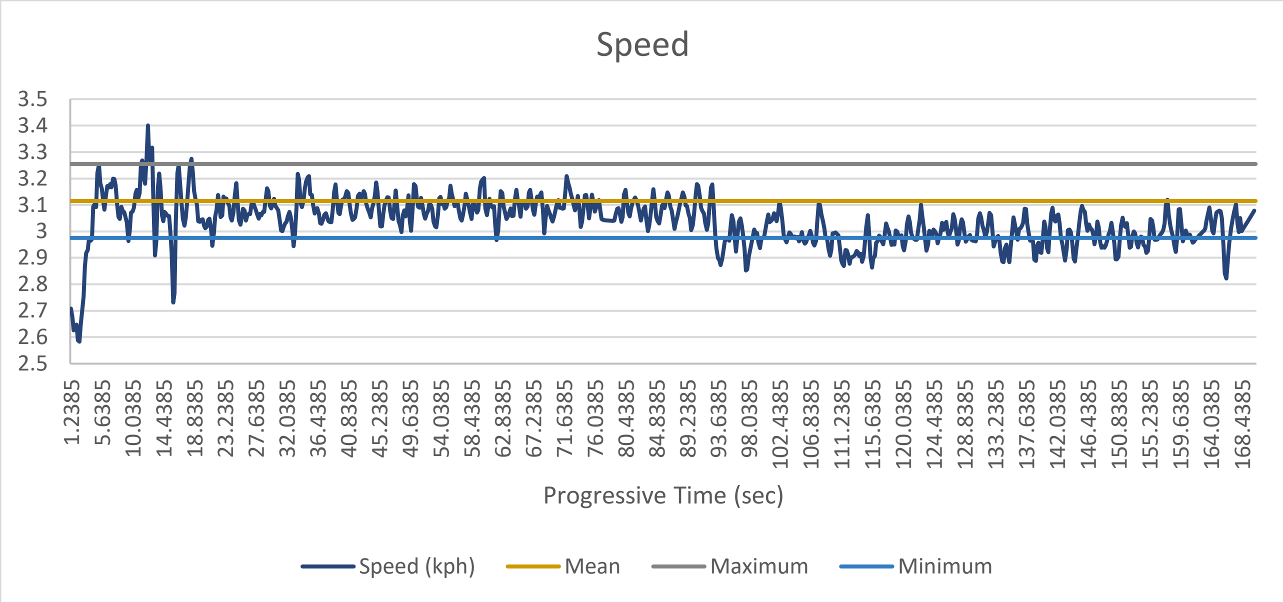
200mm – 3kph

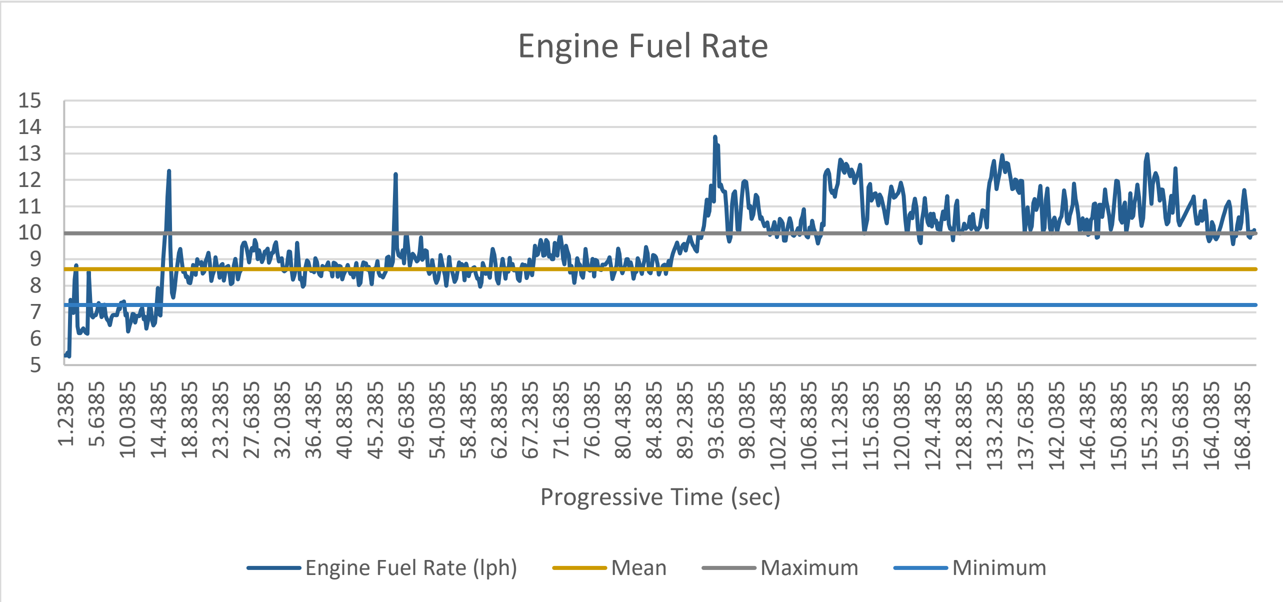


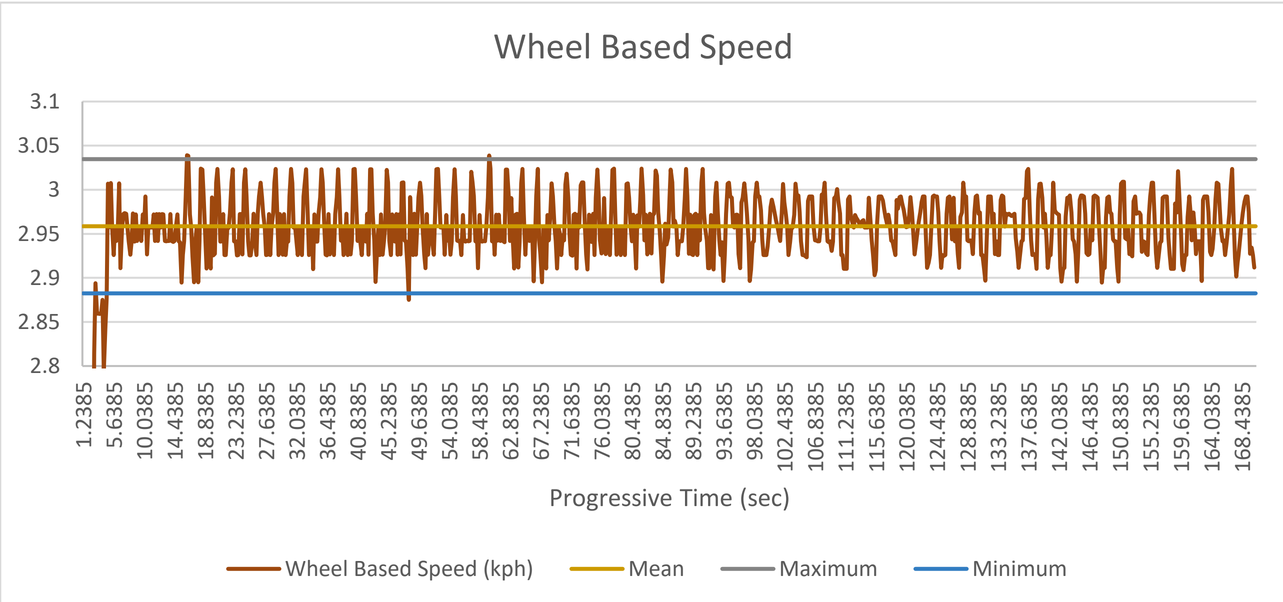
Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
Engine RPM
1.2385
6.0385
10.8385
15.6385
20.4385
25.2385
30.0385
34.8385
39.6385
44.4385
49.2385
54.0385
58.8385
63.6385
68.4385
73.2385
78.0385
82.8385
87.6385
92.4385
97.2385
102.0385
106.8385
111.6385
116.4385
121.2385
126.0385
130.8385
135.6385
140.4385
145.2385
150.0385
154.8385
159.6385
164.4385
169.2385
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

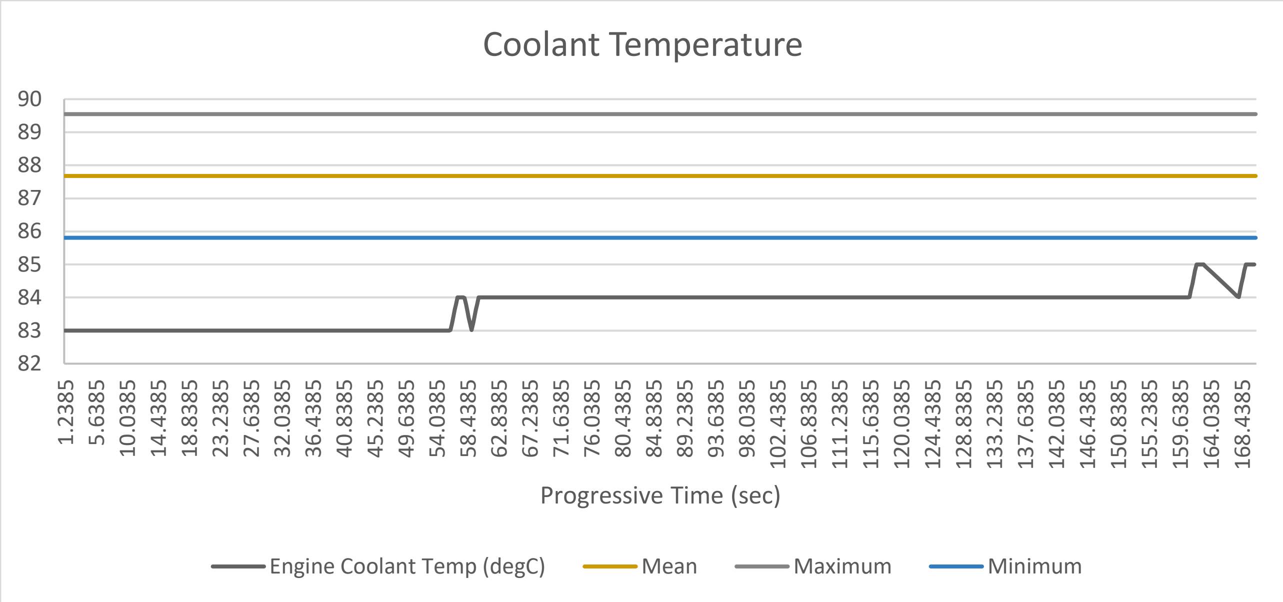


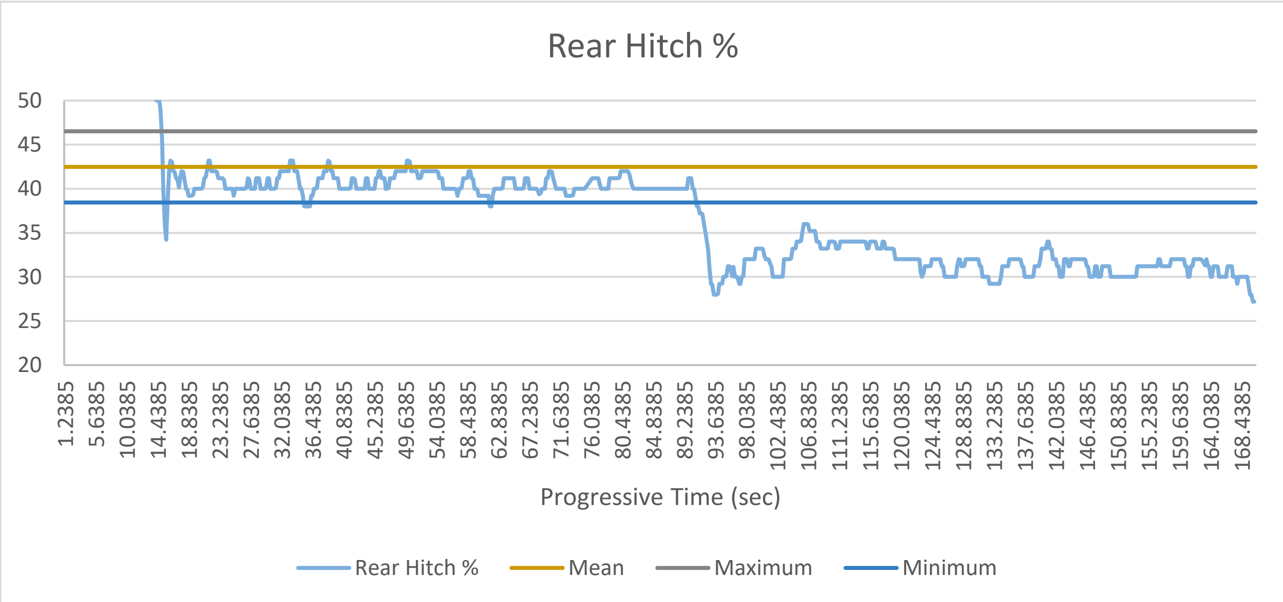
Engine Load
55
50
45
40
35
30
25
20
1.2385
5.6385
10.0385
14.4385
18.8385
23.2385
27.6385
32.0385
36.4385
40.8385
45.2385
49.6385
54.0385
58.4385
62.8385
67.2385
71.6385
76.0385
80.4385
84.8385
89.2385
93.6385
98.0385
102.4385
106.8385
111.2385
115.6385
120.0385
124.4385
128.8385
133.2385
137.6385
142.0385
146.4385
150.8385
155.2385
159.6385
164.0385
168.4385
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

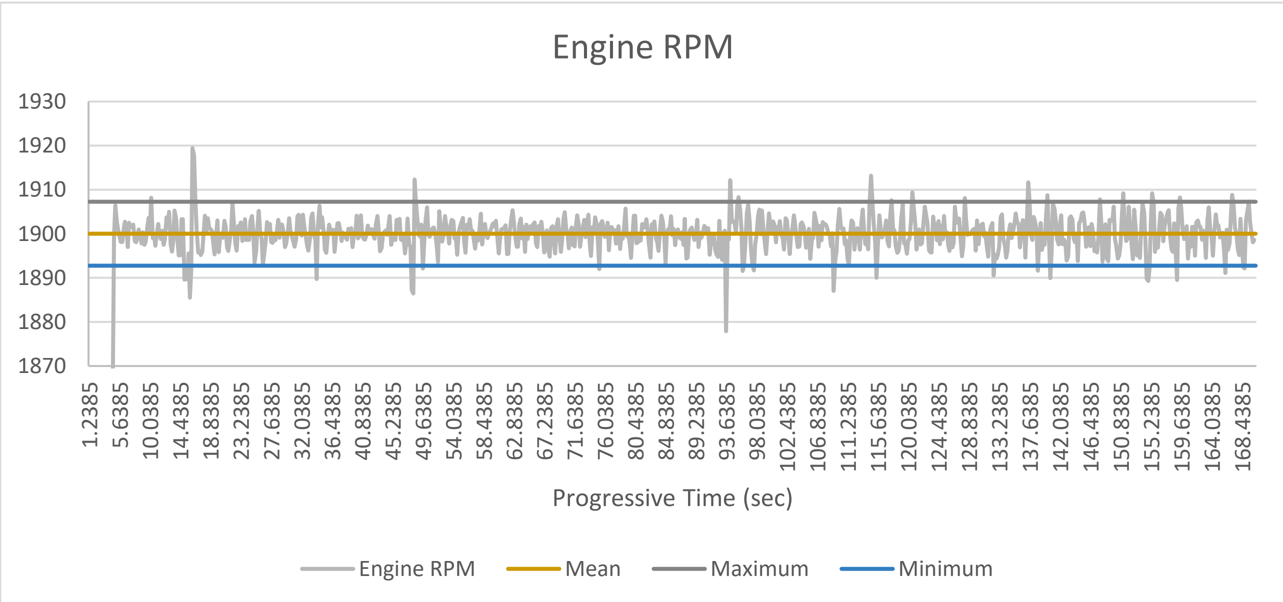

Speed
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
1.2385
5.6385
10.0385
14.4385
18.8385
23.2385
27.6385
32.0385
36.4385
40.8385
45.2385
49.6385
54.0385
58.4385
62.8385
67.2385
71.6385
76.0385
80.4385
84.8385
89.2385
93.6385
98.0385
102.4385
106.8385
111.2385
115.6385
120.0385
124.4385
128.8385
133.2385
137.6385
142.0385
146.4385
150.8385
155.2385
159.6385
164.0385
168.4385
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
15
14
13
12
11
10
9
8
7
6
5
1.2385
5.6385
10.0385
14.4385
18.8385
23.2385
27.6385
32.0385
36.4385
40.8385
45.2385
49.6385
54.0385
58.4385
62.8385
67.2385
71.6385
76.0385
80.4385
84.8385
89.2385
93.6385
98.0385
102.4385
106.8385
111.2385
115.6385
120.0385
124.4385
128.8385
133.2385
137.6385
142.0385
146.4385
150.8385
155.2385
159.6385
164.0385
168.4385
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

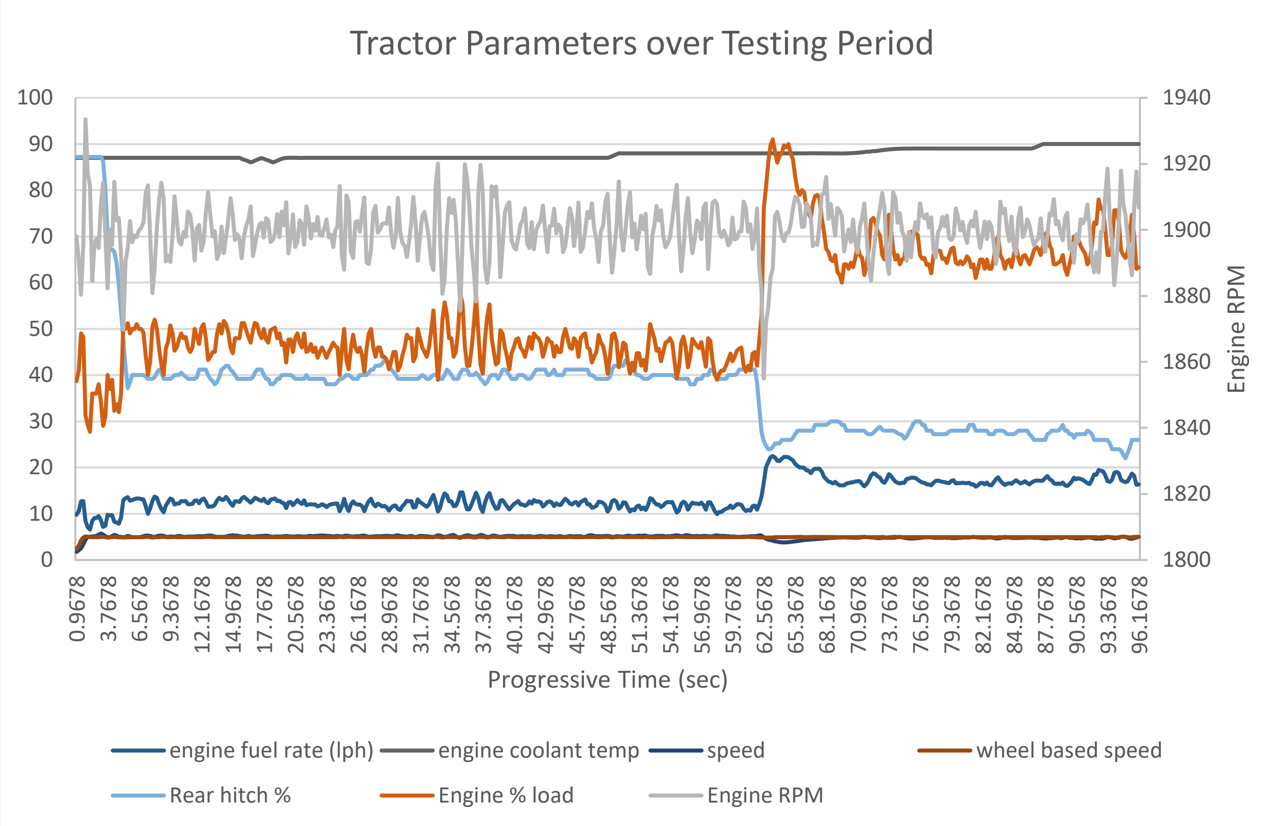

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
1.2385
5.6385
10.0385
14.4385
18.8385
23.2385
27.6385
32.0385
36.4385
40.8385
45.2385
49.6385
54.0385
58.4385
62.8385
67.2385
71.6385
76.0385
80.4385
84.8385
89.2385
93.6385
98.0385
102.4385
106.8385
111.2385
115.6385
120.0385
124.4385
128.8385
133.2385
137.6385
142.0385
146.4385
150.8385
155.2385
159.6385
164.0385
168.4385
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
89
88
87
86
85
84
83
82
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

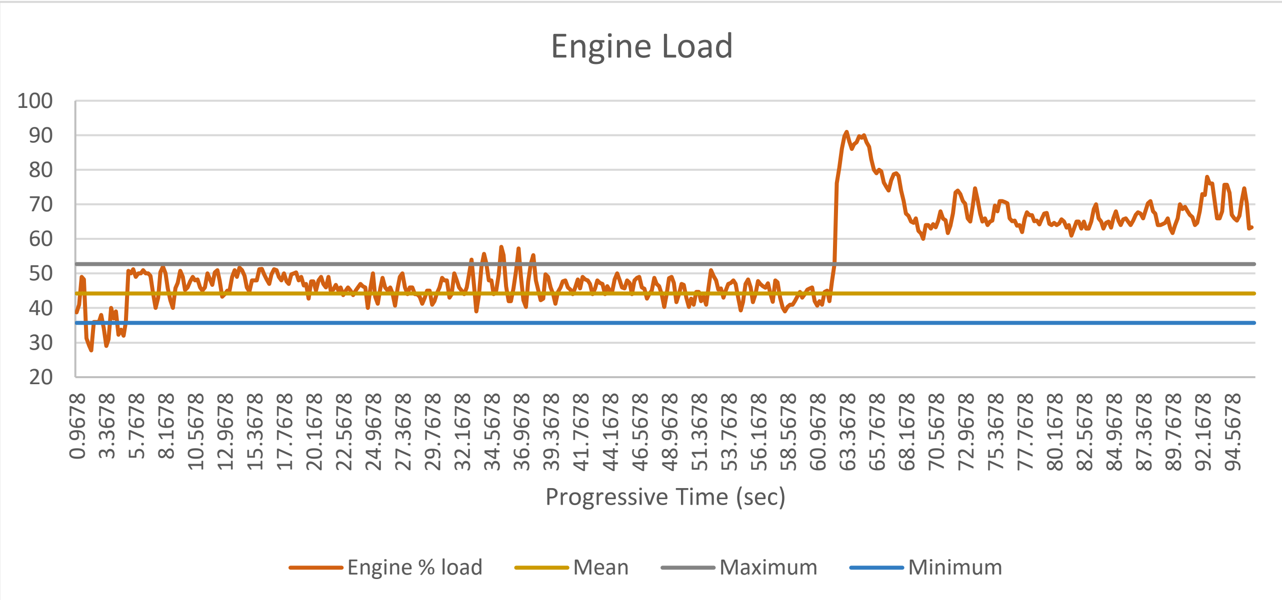

Rear Hitch %
50
45
40
35
30
25
20
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1930
1920
1910
1900
1890
1880
1870
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

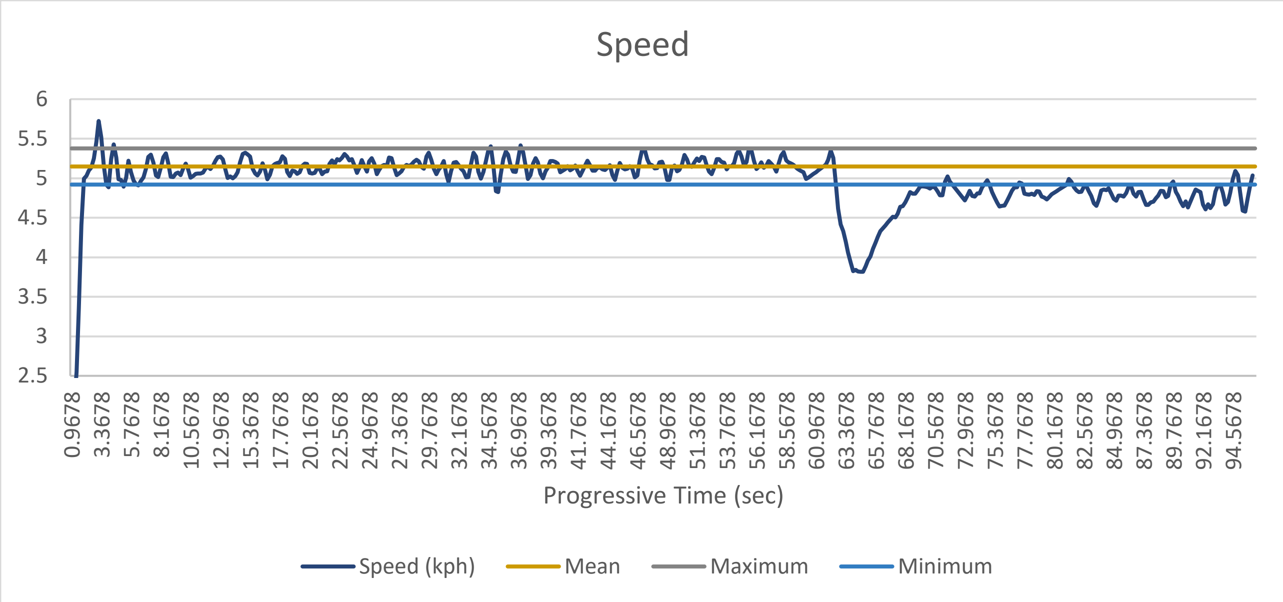
200mm – 5kph

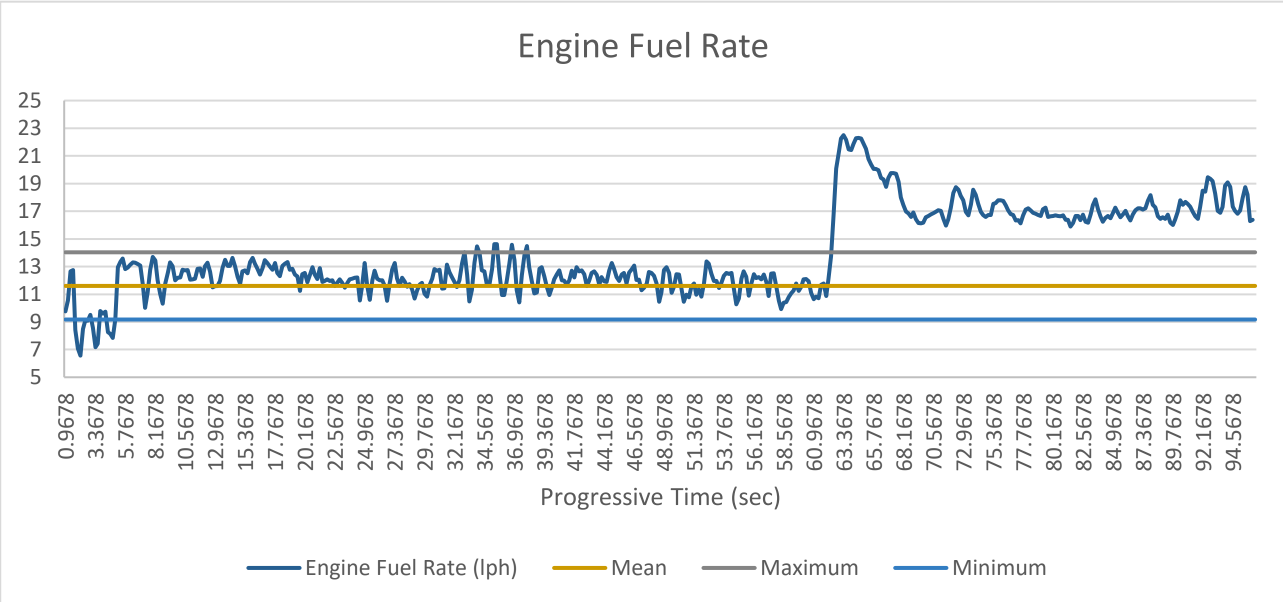


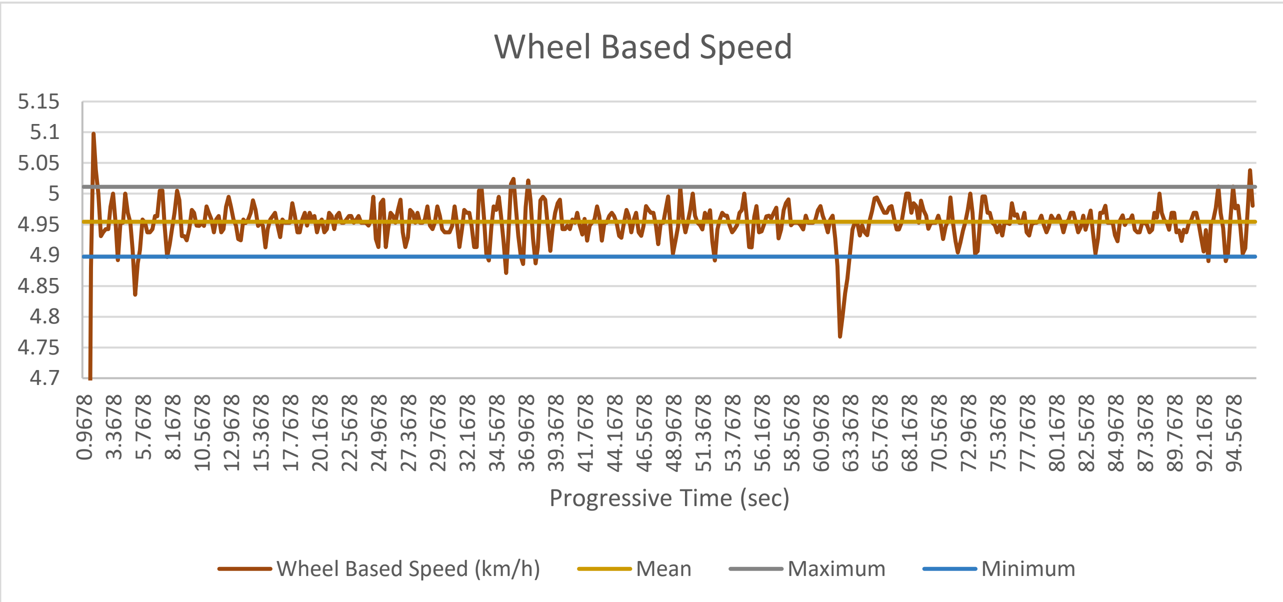
Tractor Parameters over Testing Period
100
90
80
70
60
50
40
30
20
10
0
1940
1920
1900
1880
1860
1840
1820
1800
Engine RPM
0.9678
3.7678
6.5678
9.3678
12.1678
14.9678
17.7678
20.5678
23.3678
26.1678
28.9678
31.7678
34.5678
37.3678
40.1678
42.9678
45.7678
48.5678
51.3678
54.1678
56.9678
59.7678
62.5678
65.3678
68.1678
70.9678
73.7678
76.5678
79.3678
82.1678
84.9678
87.7678
90.5678
93.3678
96.1678
Progressive Time (sec)
engine fuel rate (lph)
engine coolant temp
speed
wheel based speed
Rear hitch %
Engine % load
Engine RPM

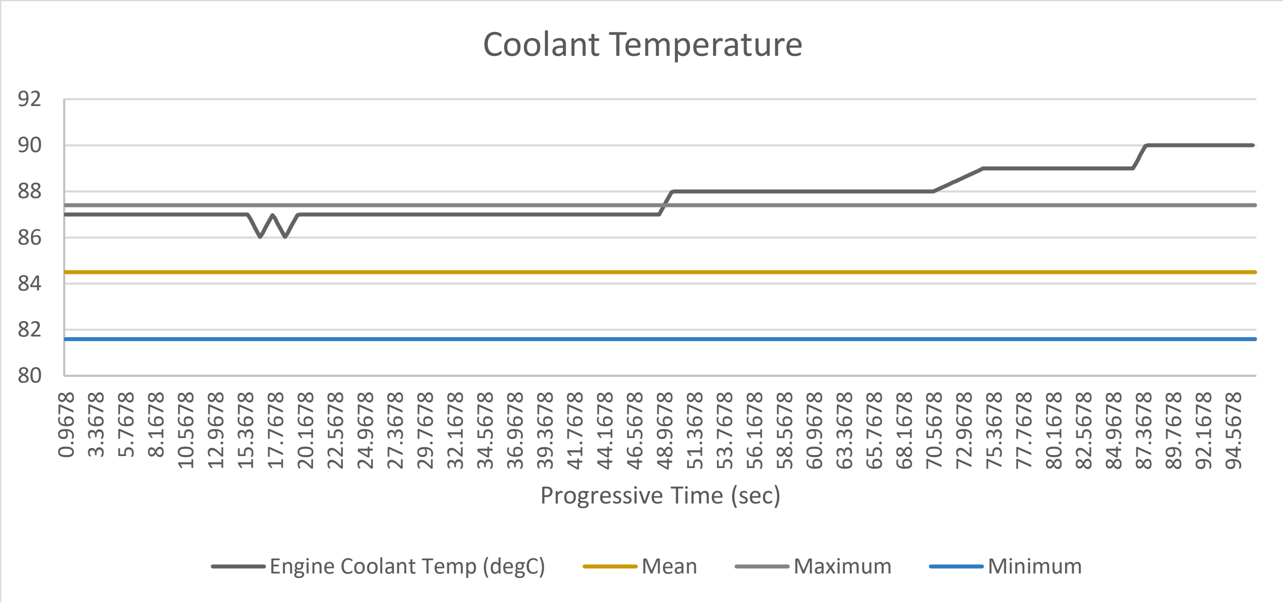


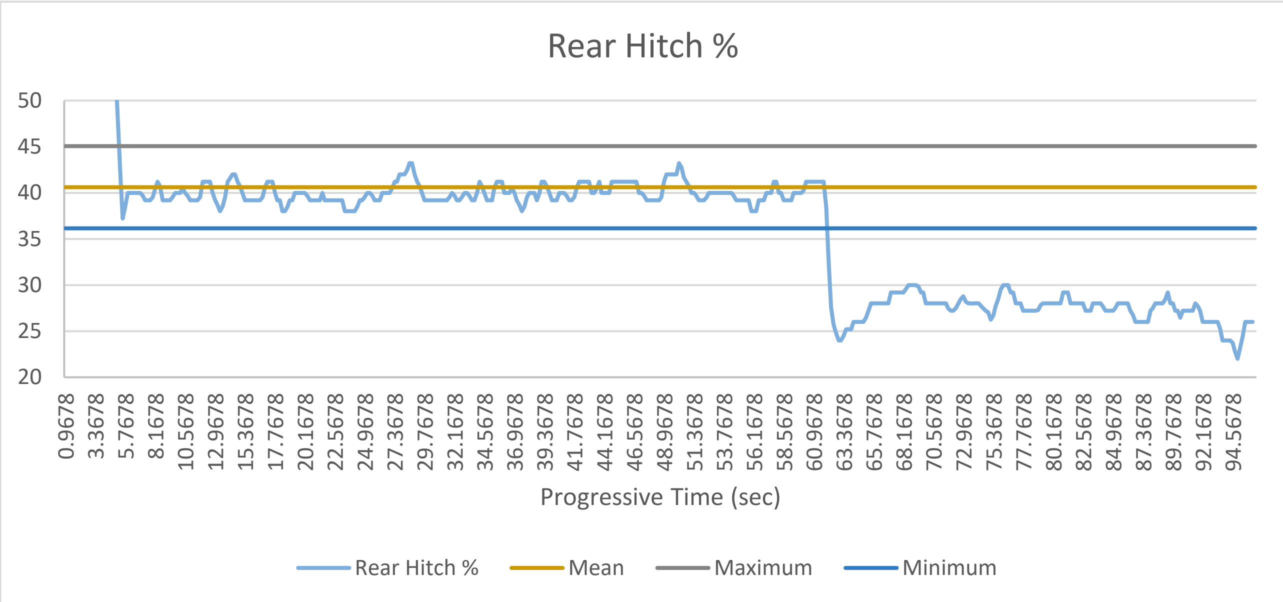
Engine Load
100
90
80
70
60
50
40
30
20
0.9678
3.3678
5.7678
8.1678
10.5678
12.9678
15.3678
17.7678
20.1678
22.5678
24.9678
27.3678
29.7678
32.1678
34.5678
36.9678
39.3678
41.7678
44.1678
46.5678
48.9678
51.3678
53.7678
56.1678
58.5678
60.9678
63.3678
65.7678
68.1678
70.5678
72.9678
75.3678
77.7678
80.1678
82.5678
84.9678
87.3678
89.7678
92.1678
94.5678
Progressive Time (sec)
Engine % load
Mean
Maximum
Minimum

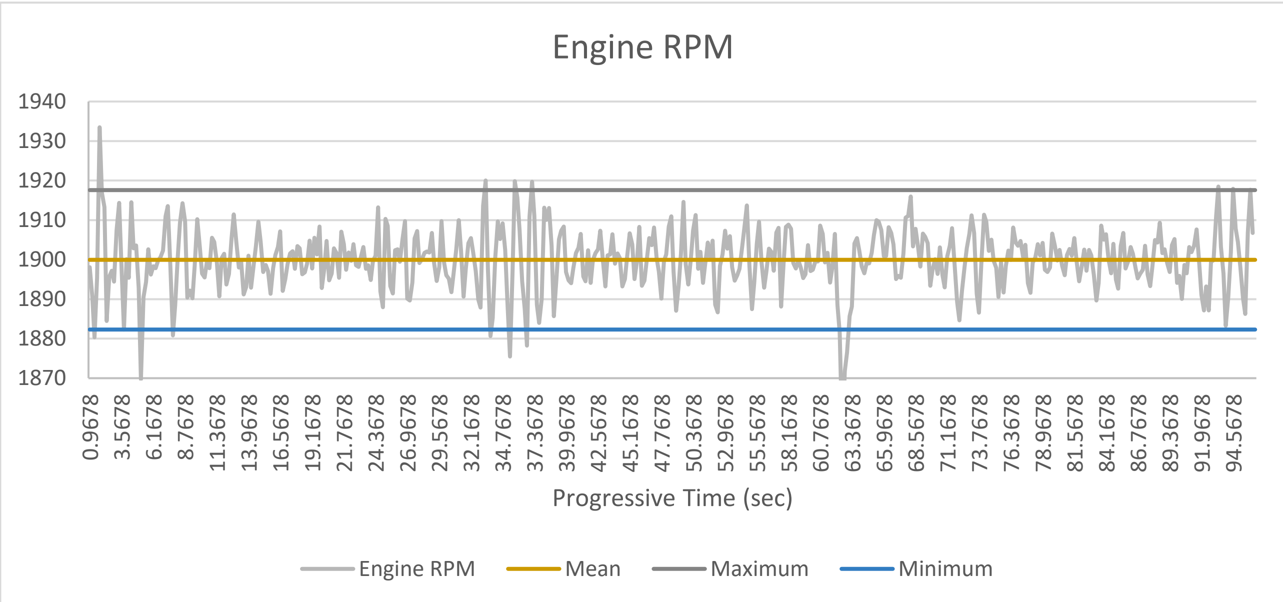

Speed
6
5.5
5
4.5
4
3.5
3
2.5
0.9678
3.3678
5.7678
8.1678
10.5678
12.9678
15.3678
17.7678
20.1678
22.5678
24.9678
27.3678
29.7678
32.1678
34.5678
36.9678
39.3678
41.7678
44.1678
46.5678
48.9678
51.3678
53.7678
56.1678
58.5678
60.9678
63.3678
65.7678
68.1678
70.5678
72.9678
75.3678
77.7678
80.1678
82.5678
84.9678
87.3678
89.7678
92.1678
94.5678
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
25
23
21
19
17
15
13
11
9
7
5
0.9678
3.3678
5.7678
8.1678
10.5678
12.9678
15.3678
17.7678
20.1678
22.5678
24.9678
27.3678
29.7678
32.1678
34.5678
36.9678
39.3678
41.7678
44.1678
46.5678
48.9678
51.3678
53.7678
56.1678
58.5678
60.9678
63.3678
65.7678
68.1678
70.5678
72.9678
75.3678
77.7678
80.1678
82.5678
84.9678
87.3678
89.7678
92.1678
94.5678
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
4.75
4.7
0.9678
3.3678
5.7678
8.1678
10.5678
12.9678
15.3678
17.7678
20.1678
22.5678
24.9678
27.3678
29.7678
32.1678
34.5678
36.9678
39.3678
41.7678
44.1678
46.5678
48.9678
51.3678
53.7678
56.1678
58.5678
60.9678
63.3678
65.7678
68.1678
70.5678
72.9678
75.3678
77.7678
80.1678
82.5678
84.9678
87.3678
89.7678
92.1678
94.5678
Progressive Time (sec)
Wheel Based Speed (km/h)
Mean
Maximum
Minimum

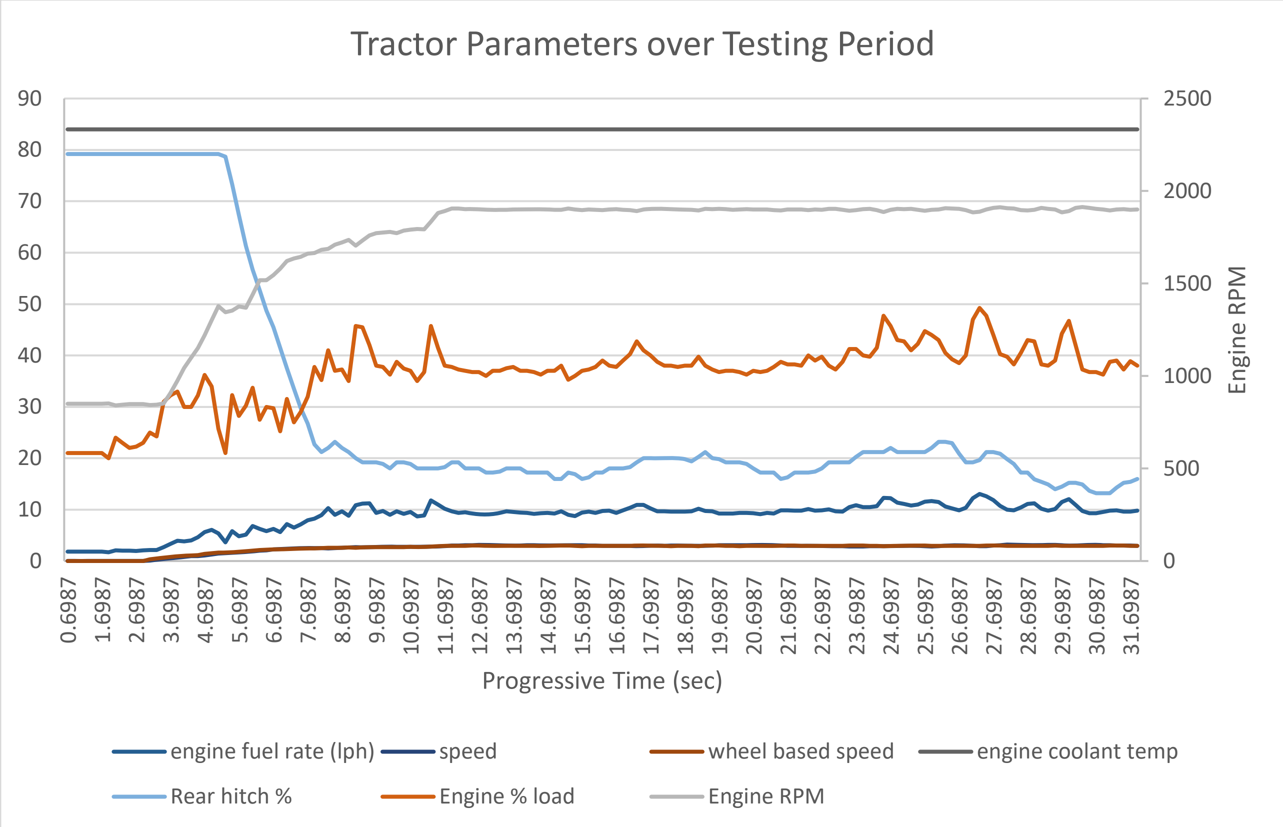

Coolant Temperature
92
90
88
86
84
82
80
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

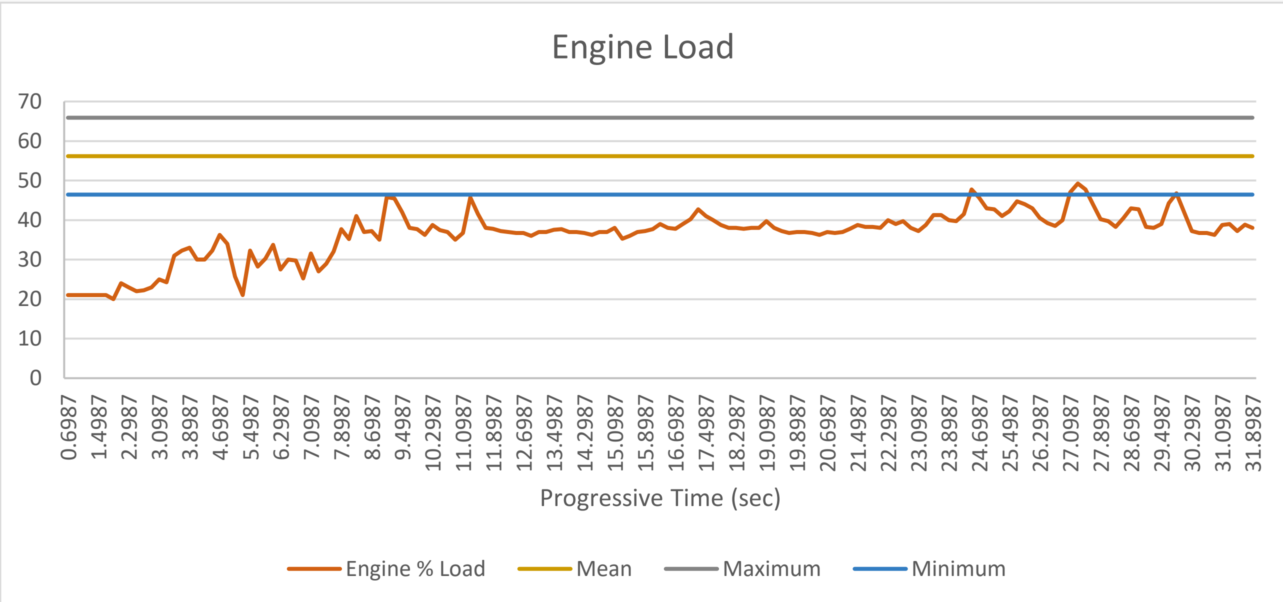

Rear Hitch %
50
45
40
35
30
25
20
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

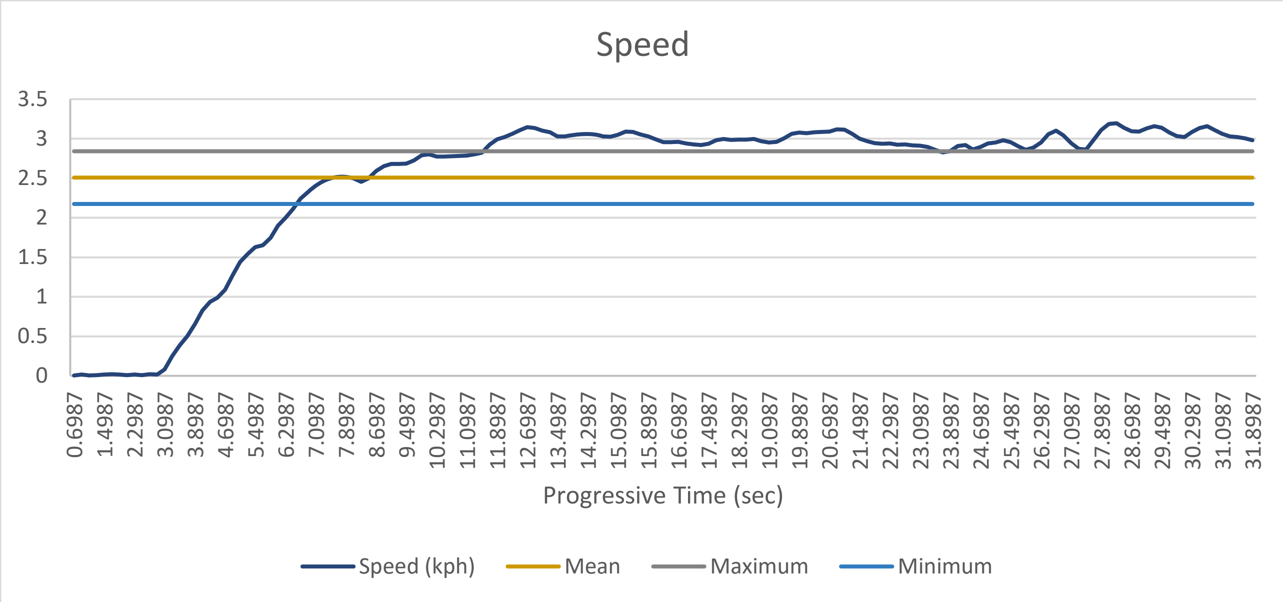

Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

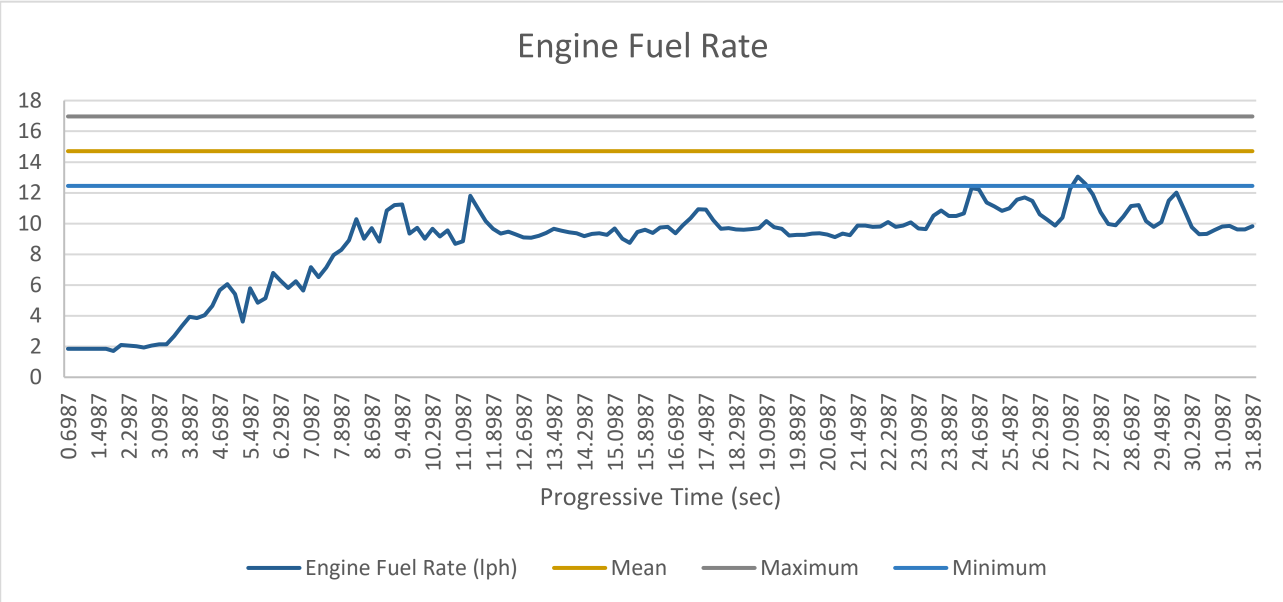
Appendix I – 3PL Deep Ripper – Bridging occurring across tines data

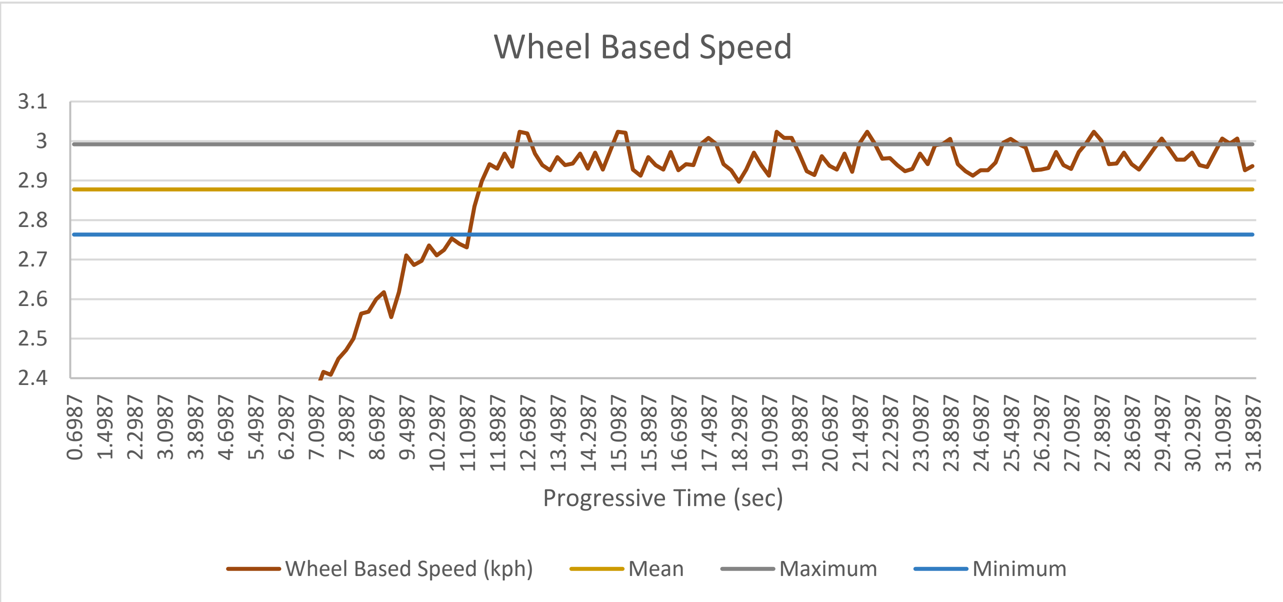
350mm – 3kph

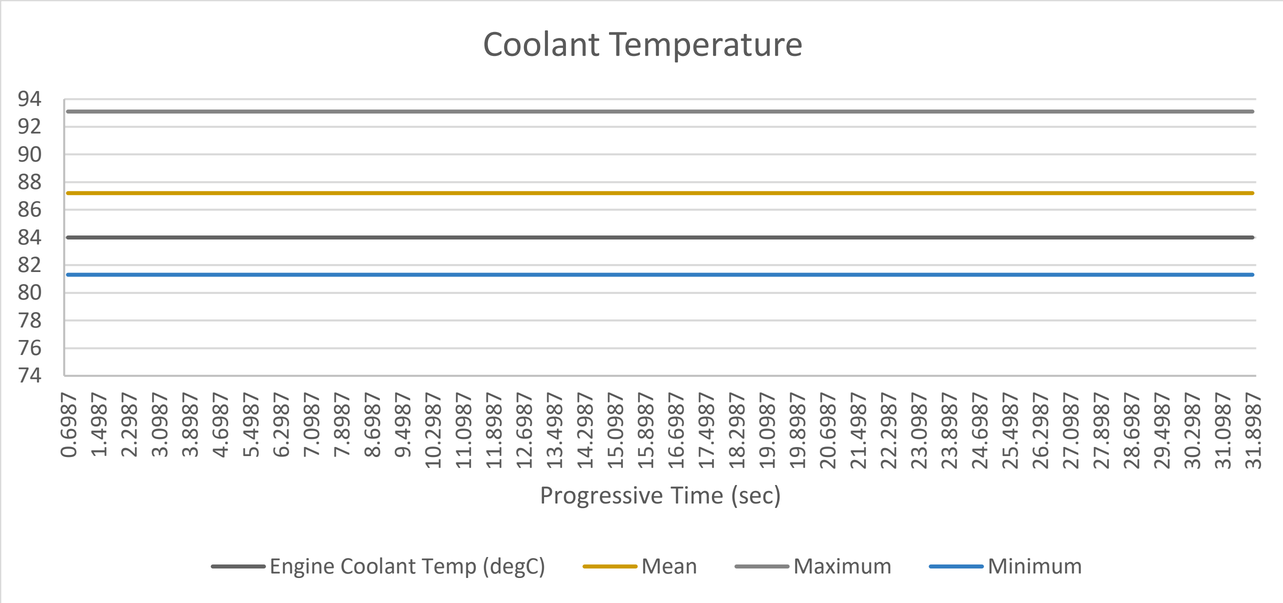


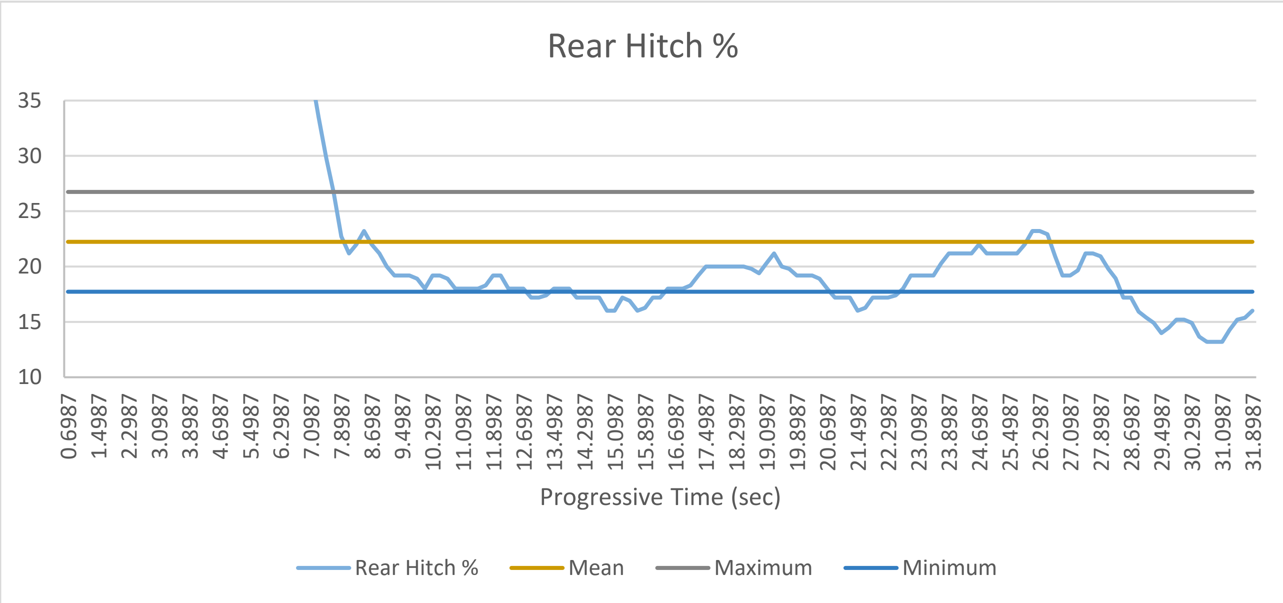


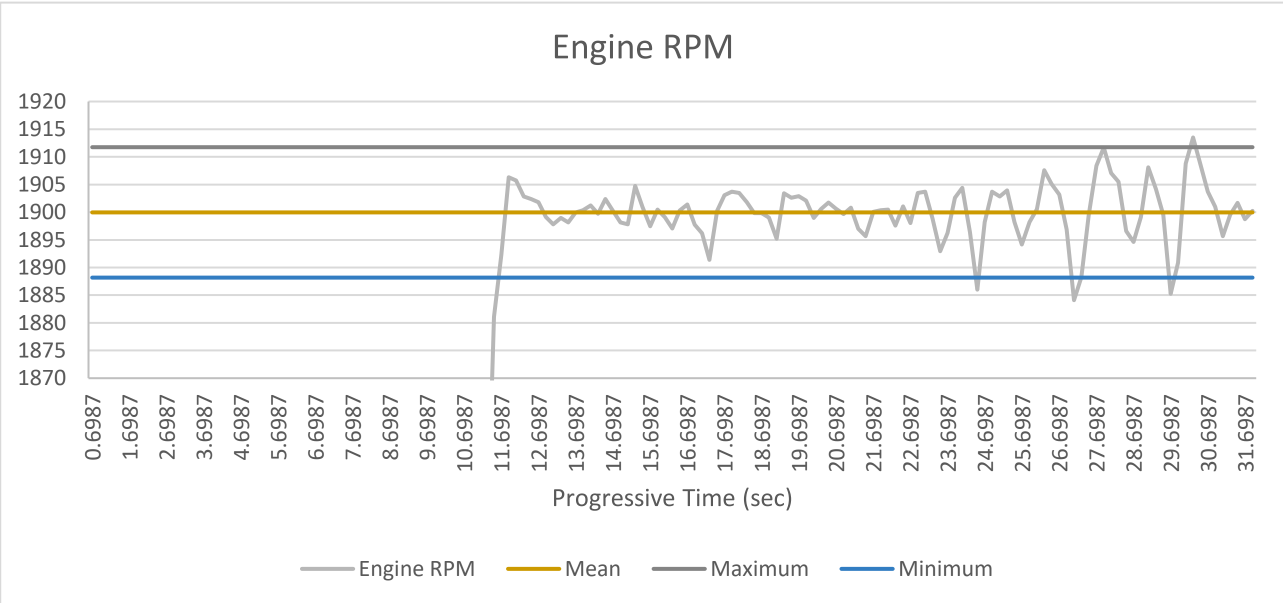

Speed
3.5
3
2.5
2
1.5
1
0.5
0
0.6987
1.4987
2.2987
3.0987
3.8987
4.6987
5.4987
6.2987
7.0987
7.8987
8.6987
9.4987
10.2987
11.0987
11.8987
12.6987
13.4987
14.2987
15.0987
15.8987
16.6987
17.4987
18.2987
19.0987
19.8987
20.6987
21.4987
22.2987
23.0987
23.8987
24.6987
25.4987
26.2987
27.0987
27.8987
28.6987
29.4987
30.2987
31.0987
31.8987
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
18
16
14
12
10
8
6
4
2
0
0.6987
1.4987
2.2987
3.0987
3.8987
4.6987
5.4987
6.2987
7.0987
7.8987
8.6987
9.4987
10.2987
11.0987
11.8987
12.6987
13.4987
14.2987
15.0987
15.8987
16.6987
17.4987
18.2987
19.0987
19.8987
20.6987
21.4987
22.2987
23.0987
23.8987
24.6987
25.4987
26.2987
27.0987
27.8987
28.6987
29.4987
30.2987
31.0987
31.8987
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

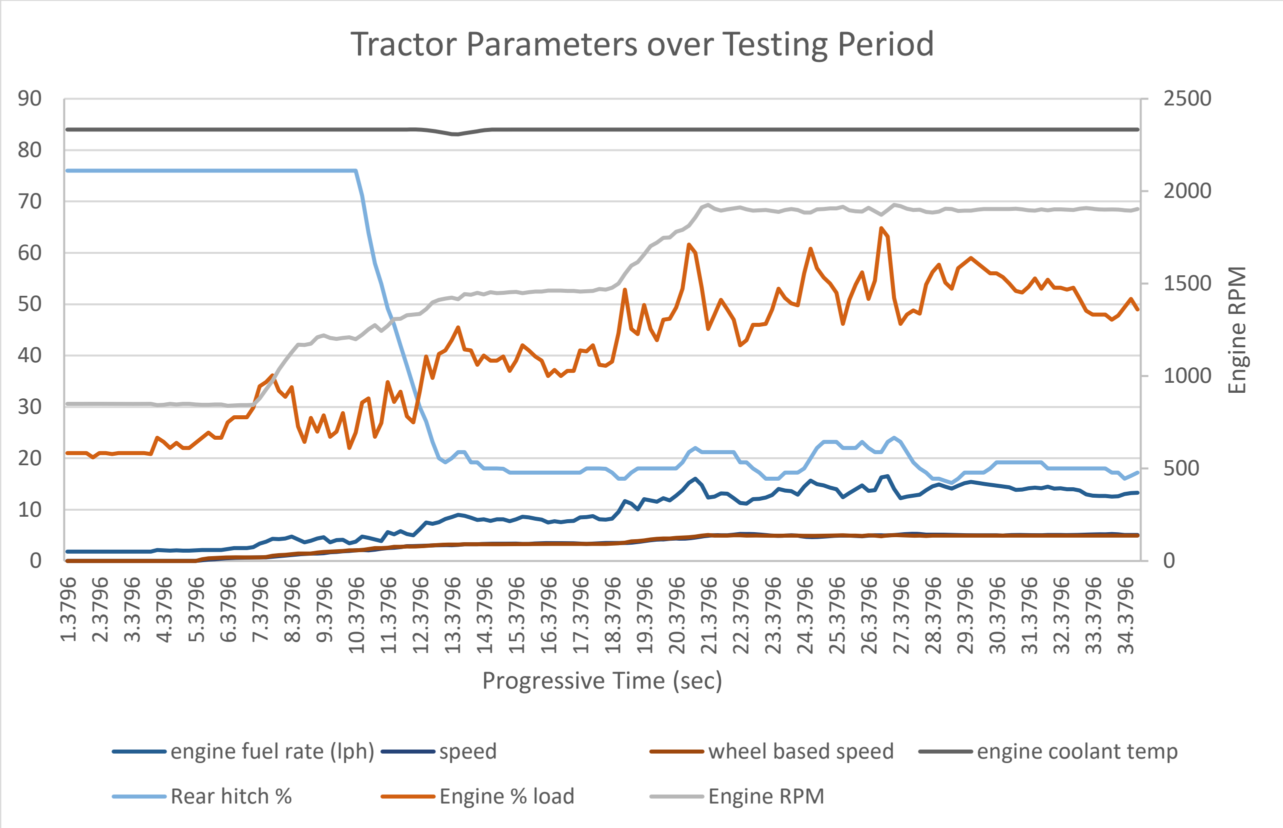

Wheel Based Speed
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
0.6987
1.4987
2.2987
3.0987
3.8987
4.6987
5.4987
6.2987
7.0987
7.8987
8.6987
9.4987
10.2987
11.0987
11.8987
12.6987
13.4987
14.2987
15.0987
15.8987
16.6987
17.4987
18.2987
19.0987
19.8987
20.6987
21.4987
22.2987
23.0987
23.8987
24.6987
25.4987
26.2987
27.0987
27.8987
28.6987
29.4987
30.2987
31.0987
31.8987
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
94
92
90
88
86
84
82
80
78
76
74
0.6987 1.4987 2.2987 3.0987 3.8987 4.6987 5.4987 6.2987 7.0987 7.8987 8.6987 9.4987 10.2987 11.0987 11.8987 12.6987 13.4987 14.2987 15.0987 15.8987 16.6987 17.4987 18.2987 19.0987 19.8987 20.6987 21.4987 22.2987 23.0987 23.8987 24.6987 25.4987 26.2987 27.0987 27.8987 28.6987 29.4987 30.2987 31.0987 31.8987
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

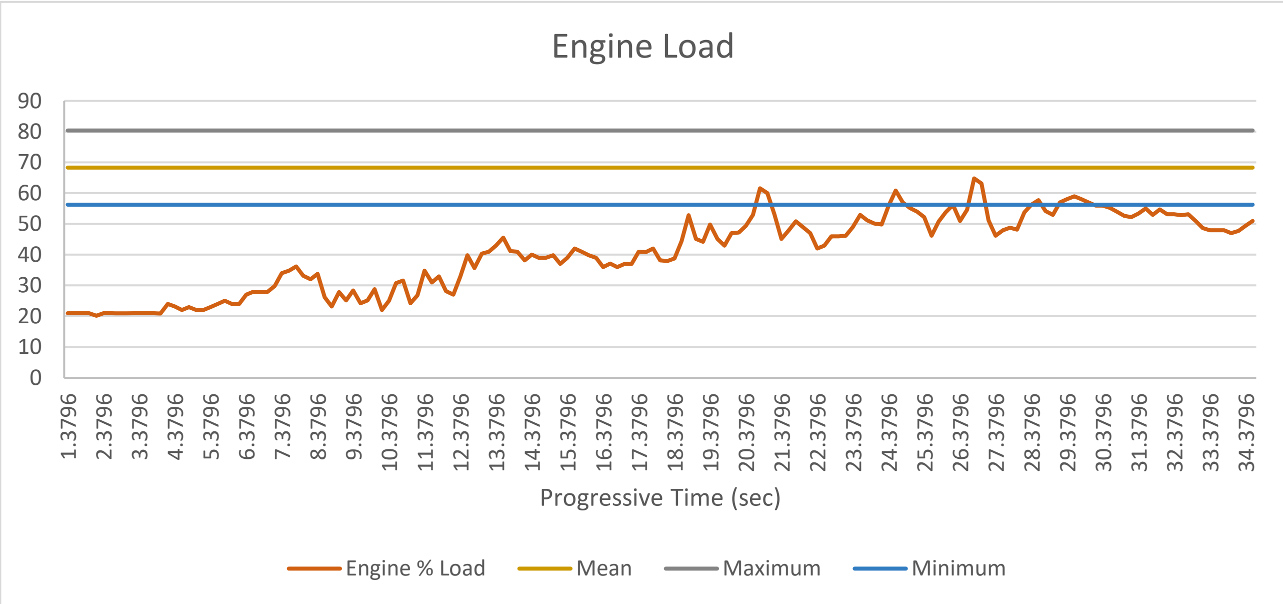

Rear Hitch %
35
30
25
20
15
10
0.6987 1.4987 2.2987 3.0987 3.8987 4.6987 5.4987 6.2987 7.0987 7.8987 8.6987 9.4987 10.2987 11.0987 11.8987 12.6987 13.4987 14.2987 15.0987 15.8987 16.6987 17.4987 18.2987 19.0987 19.8987 20.6987 21.4987 22.2987 23.0987 23.8987 24.6987 25.4987 26.2987 27.0987 27.8987 28.6987 29.4987 30.2987 31.0987 31.8987
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1920
1915
1910
1905
1900
1895
1890
1885
1880
1875
1870
0.6987 1.6987 2.6987 3.6987 4.6987 5.6987 6.6987 7.6987 8.6987 9.6987 10.6987 11.6987 12.6987 13.6987 14.6987 15.6987 16.6987 17.6987 18.6987 19.6987 20.6987 21.6987 22.6987 23.6987 24.6987 25.6987 26.6987 27.6987 28.6987 29.6987 30.6987 31.6987
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

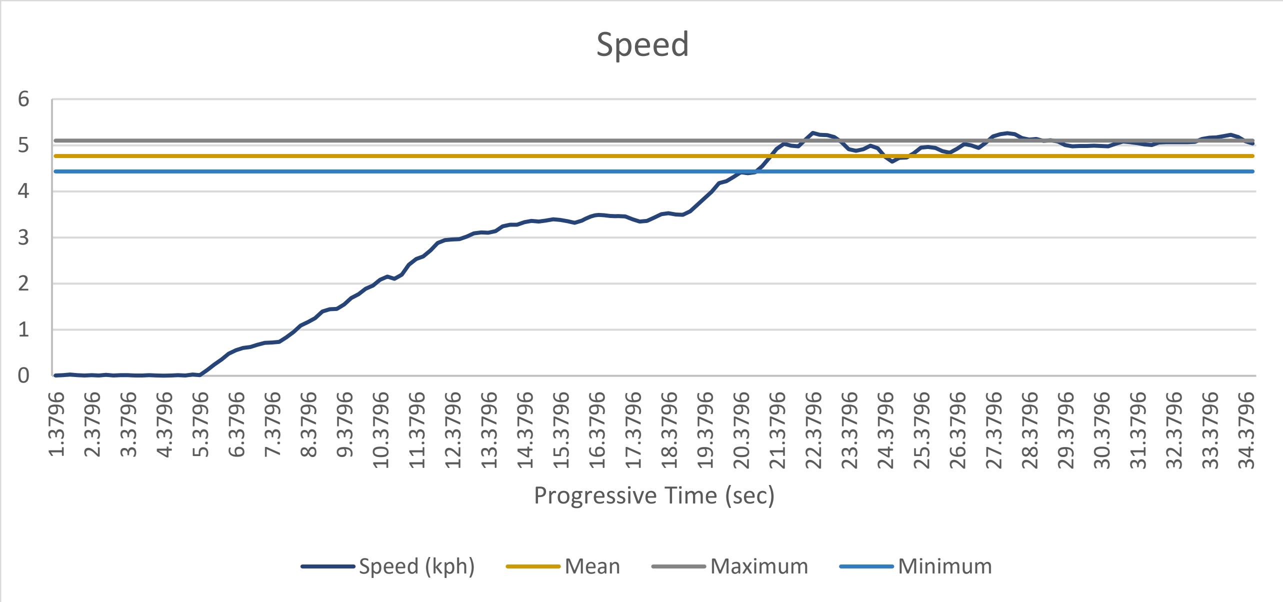
350mm – 5kph

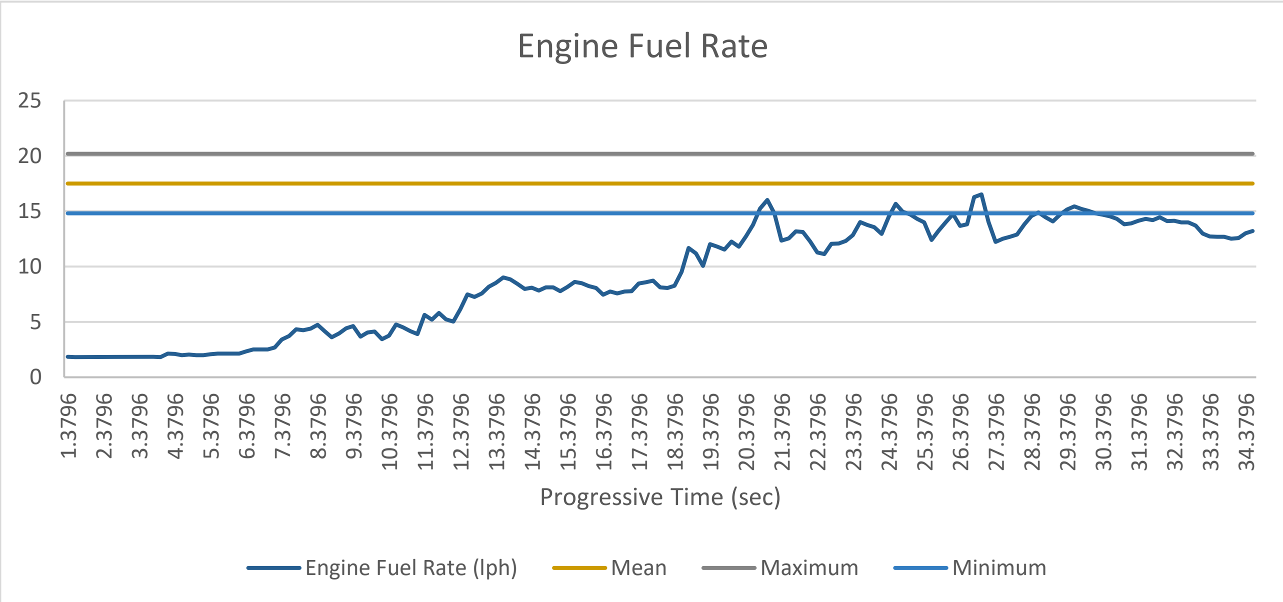


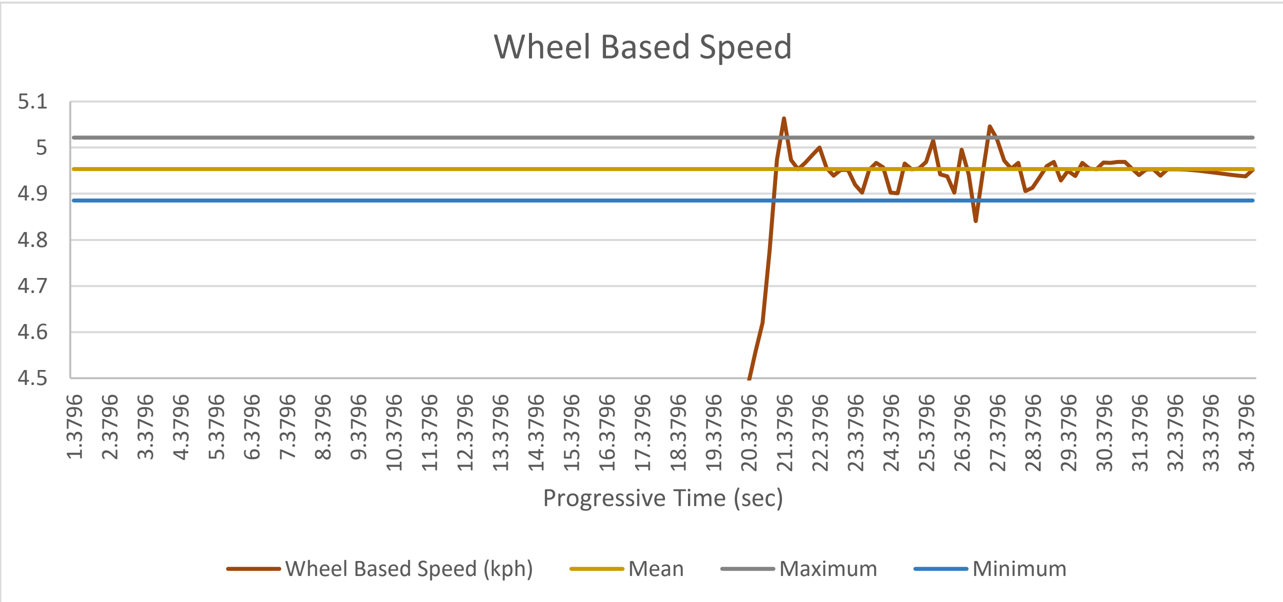
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Engine RPM
1.3796
2.3796
3.3796
4.3796
5.3796
6.3796
7.3796
8.3796
9.3796
10.3796
11.3796
12.3796
13.3796
14.3796
15.3796
16.3796
17.3796
18.3796
19.3796
20.3796
21.3796
22.3796
23.3796
24.3796
25.3796
26.3796
27.3796
28.3796
29.3796
30.3796
31.3796
32.3796
33.3796
34.3796
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

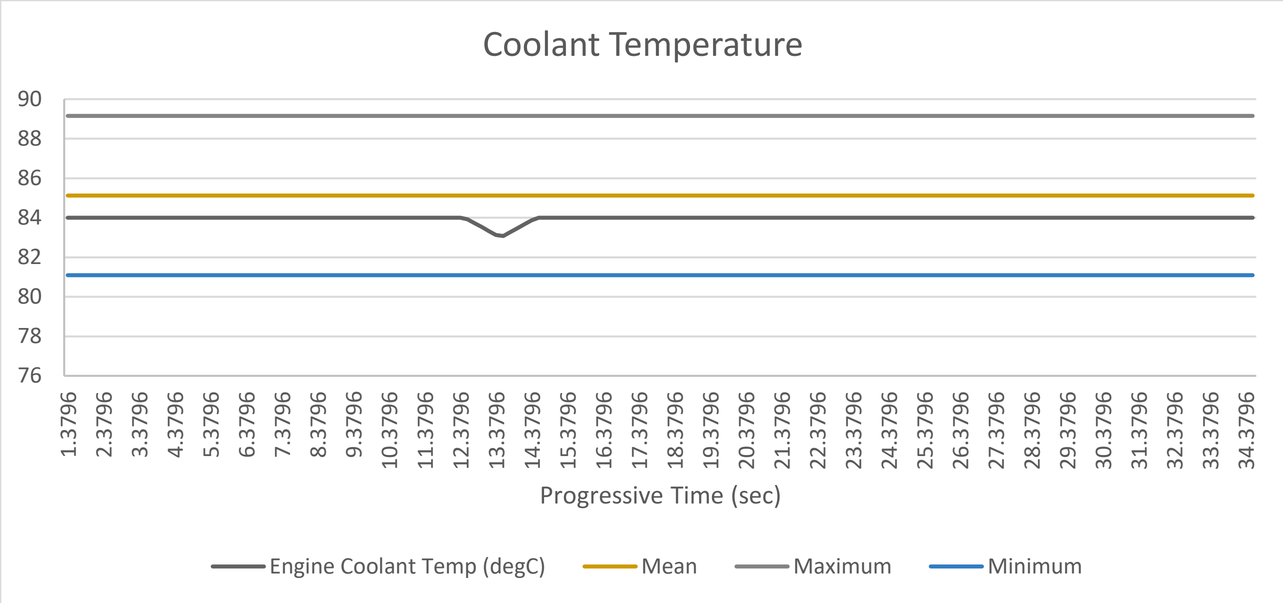


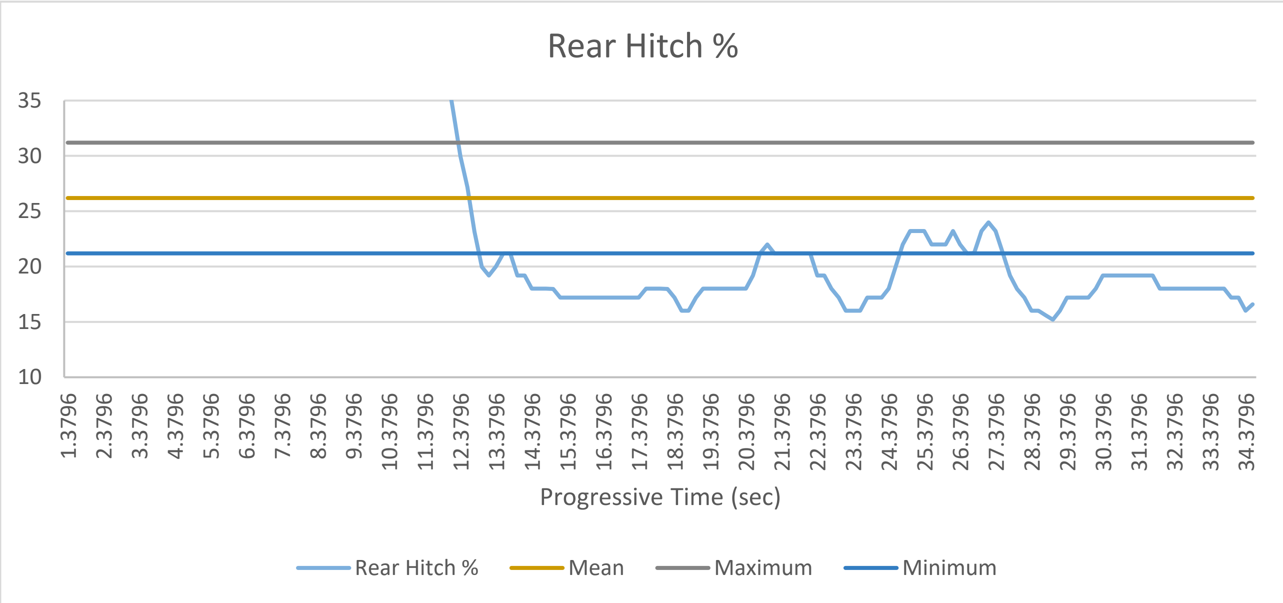
Engine Load
90
80
70
60
50
40
30
20
10
0
1.3796
2.3796
3.3796
4.3796
5.3796
6.3796
7.3796
8.3796
9.3796
10.3796
11.3796
12.3796
13.3796
14.3796
15.3796
16.3796
17.3796
18.3796
19.3796
20.3796
21.3796
22.3796
23.3796
24.3796
25.3796
26.3796
27.3796
28.3796
29.3796
30.3796
31.3796
32.3796
33.3796
34.3796
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

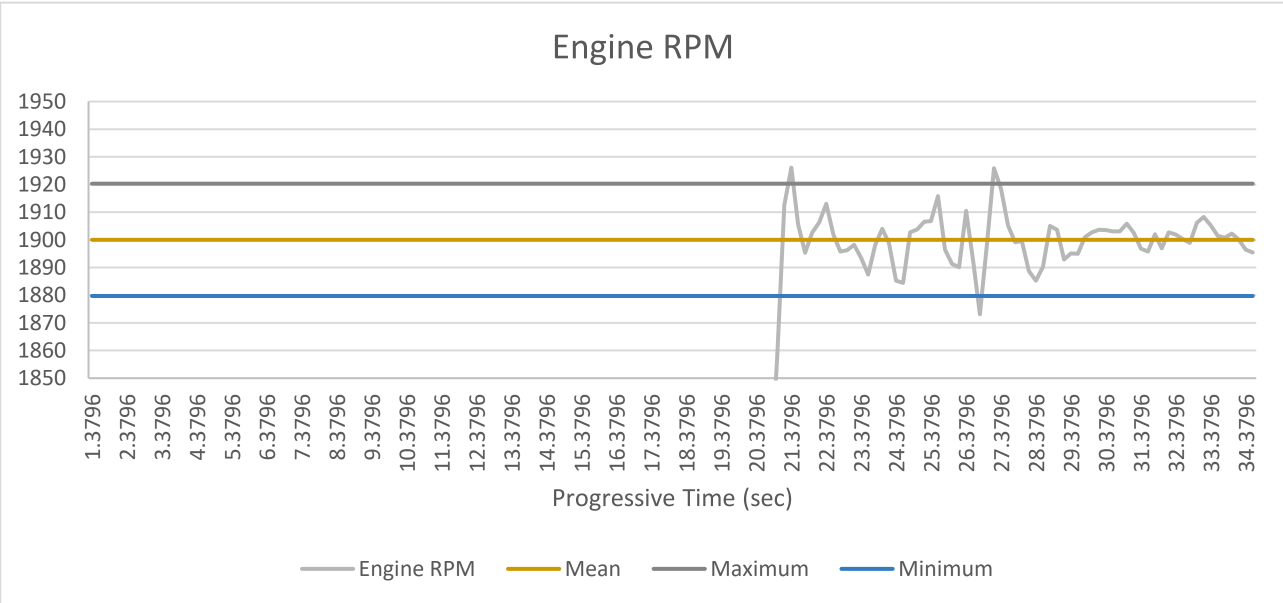

Speed
6
5
4
3
2
1
0
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
25
20
15
10
5
0
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

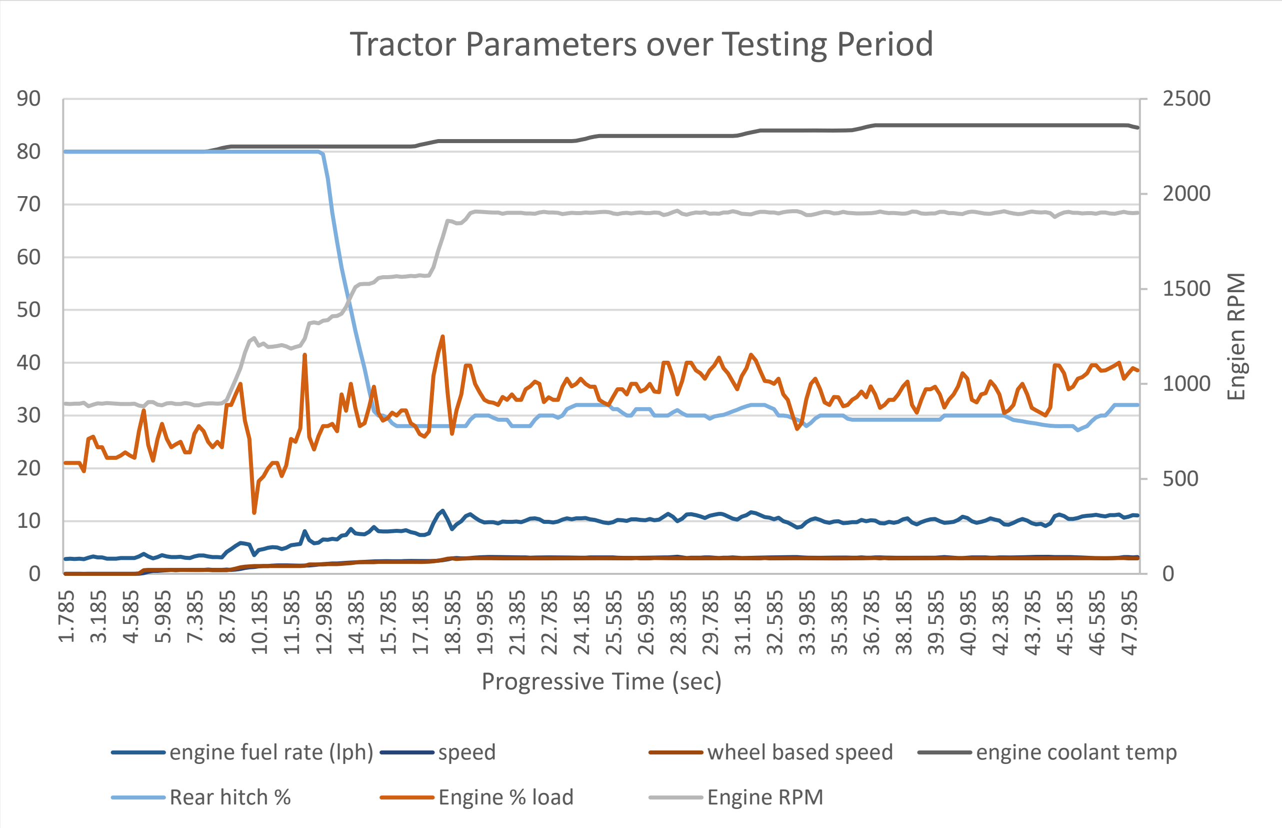

Wheel Based Speed
5.1
5
4.9
4.8
4.7
4.6
4.5
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

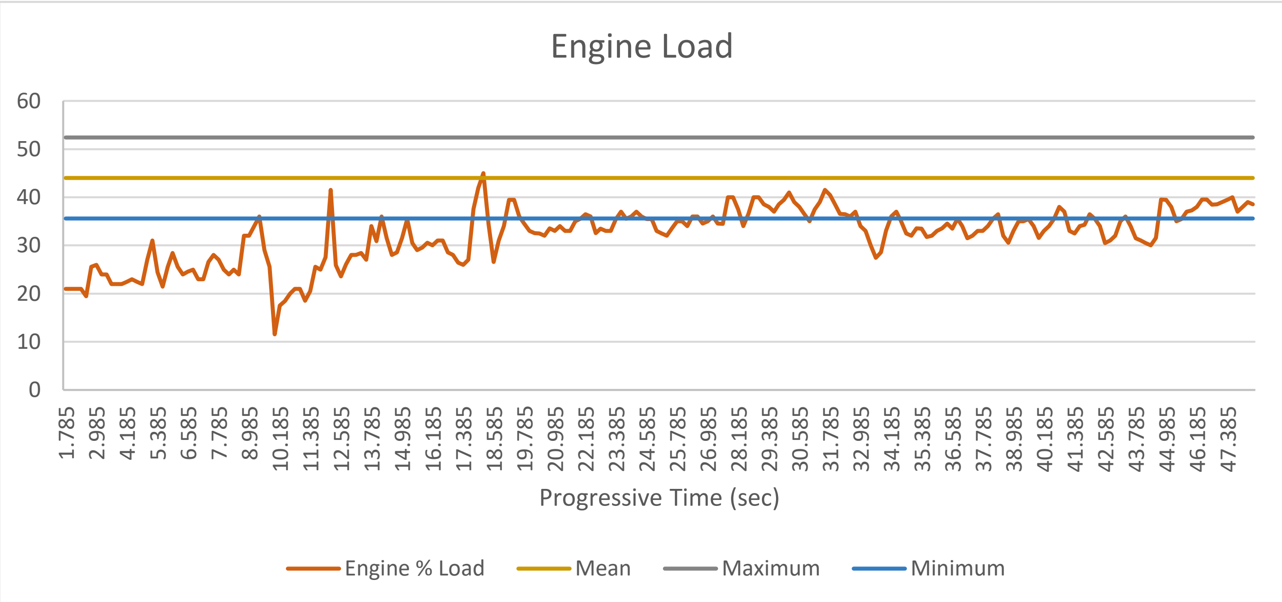

Coolant Temperature
90
88
86
84
82
80
78
76
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

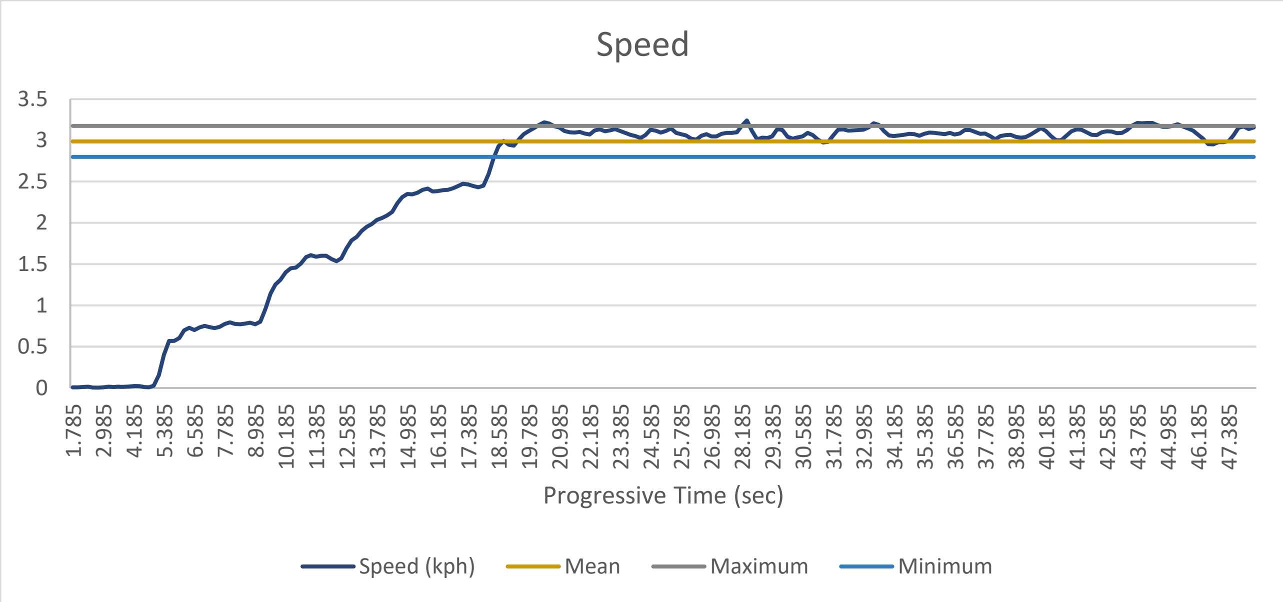

Rear Hitch %
35
30
25
20
15
10
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

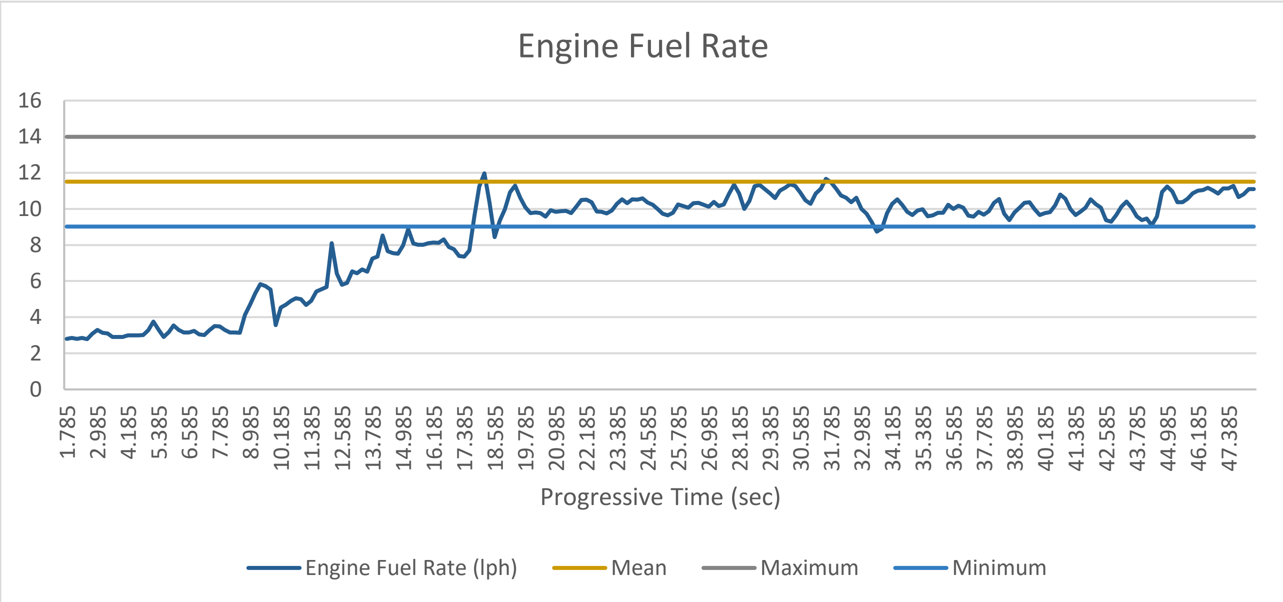

Engine RPM
1950
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1.3796 2.3796 3.3796 4.3796 5.3796 6.3796 7.3796 8.3796 9.3796 10.3796 11.3796 12.3796 13.3796 14.3796 15.3796 16.3796 17.3796 18.3796 19.3796 20.3796 21.3796 22.3796 23.3796 24.3796 25.3796 26.3796 27.3796 28.3796 29.3796 30.3796 31.3796 32.3796 33.3796 34.3796
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

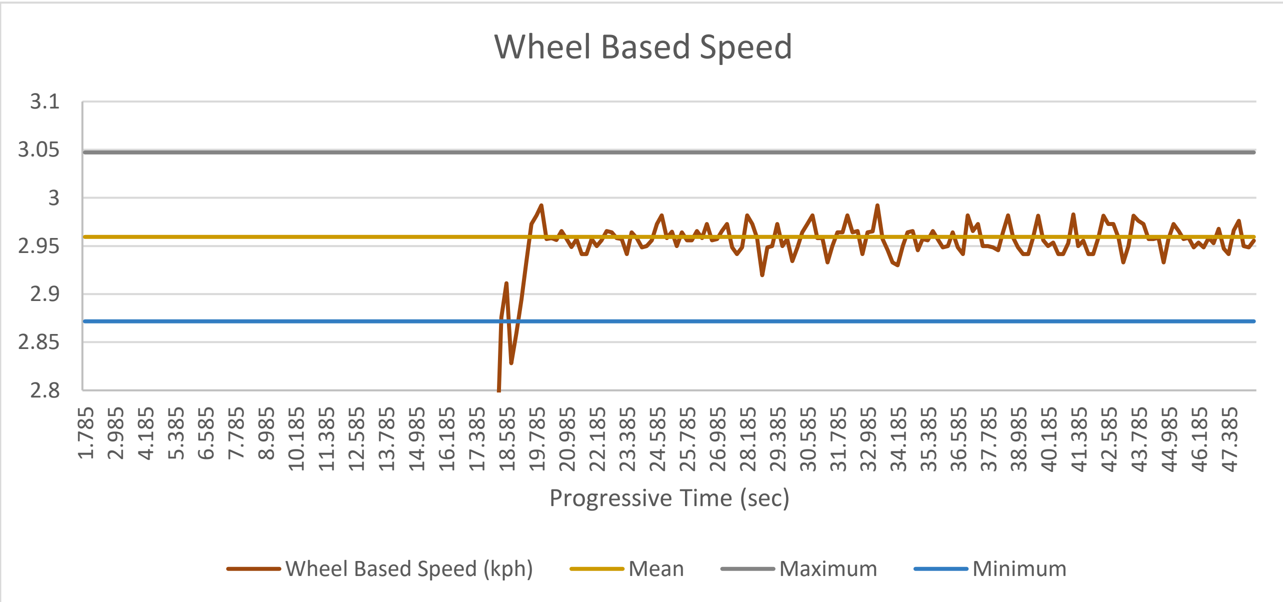
300mm – 3kph

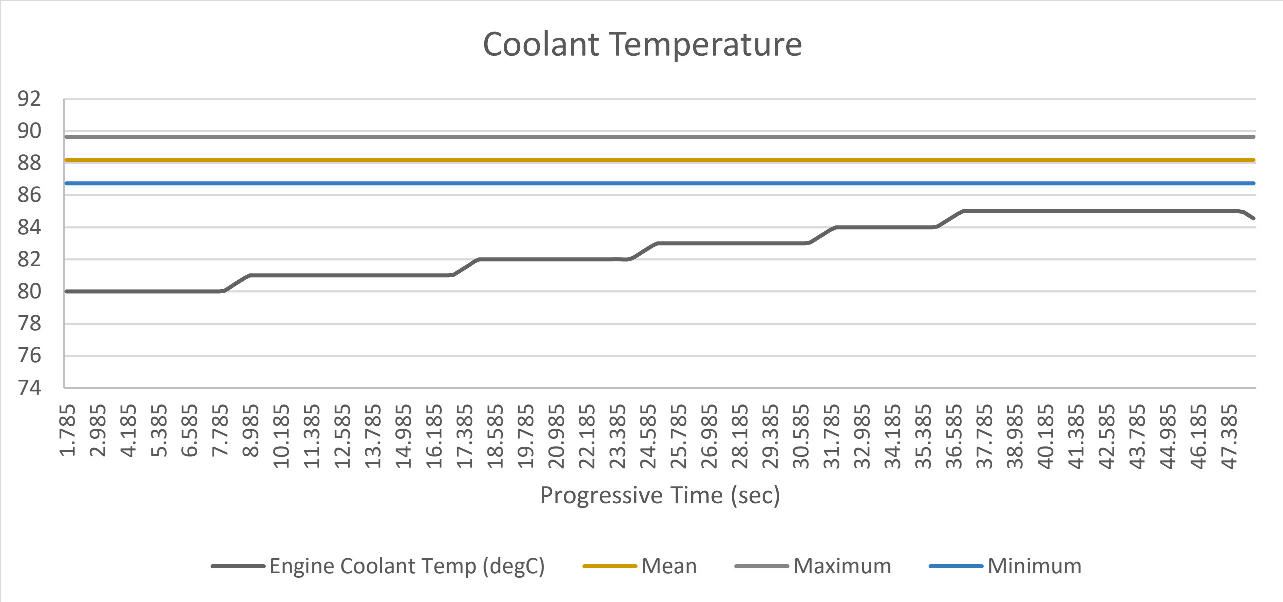

Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Engien RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

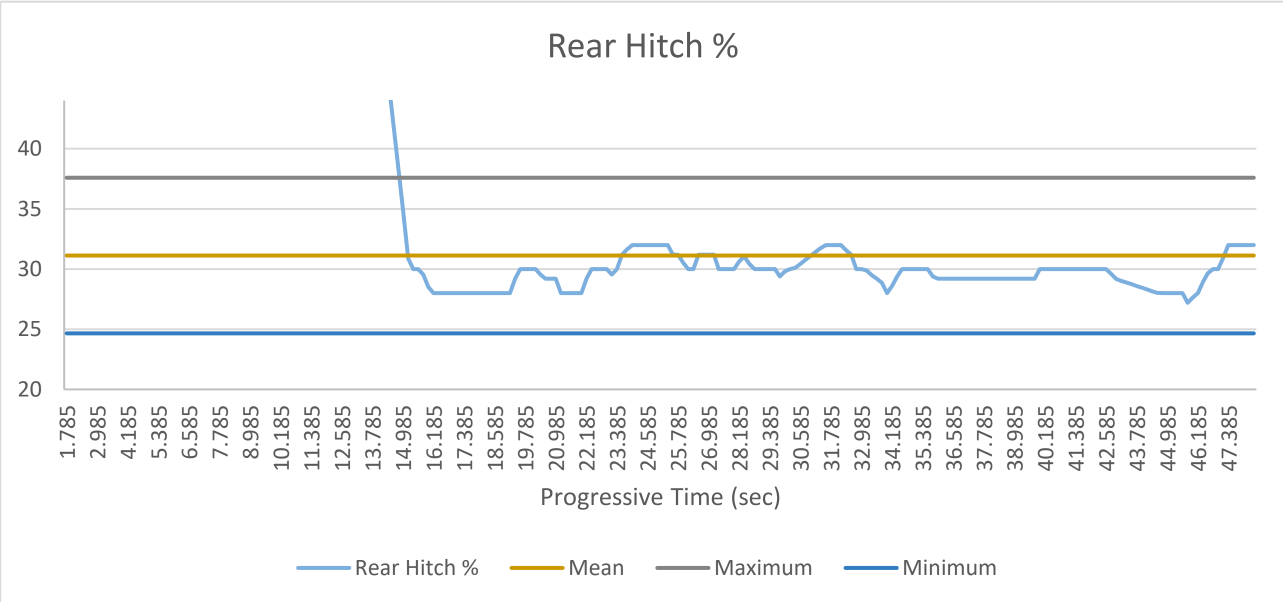

Engine Load
60
50
40
30
20
10
0
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

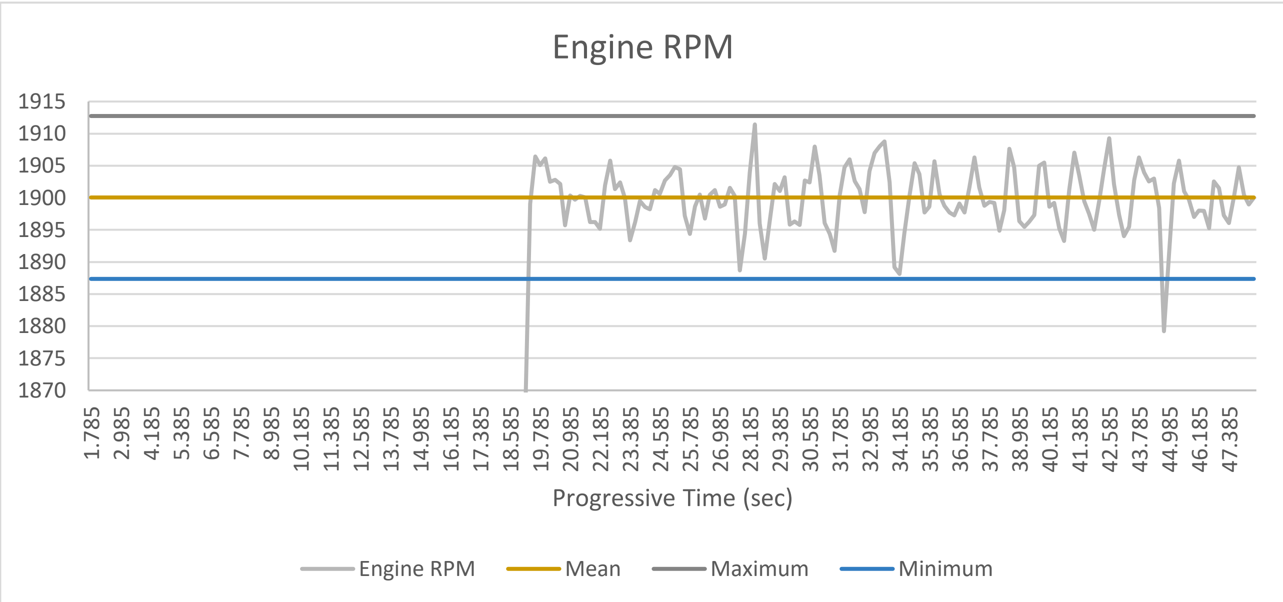

Speed
3.5
3
2.5
2
1.5
1
0.5
0
1.785
2.985
4.185
5.385
6.585
7.785
8.985
10.185
11.385
12.585
13.785
14.985
16.185
17.385
18.585
19.785
20.985
22.185
23.385
24.585
25.785
26.985
28.185
29.385
30.585
31.785
32.985
34.185
35.385
36.585
37.785
38.985
40.185
41.385
42.585
43.785
44.985
46.185
47.385
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
16
14
12
10
8
6
4
2
0
1.785
2.985
4.185
5.385
6.585
7.785
8.985
10.185
11.385
12.585
13.785
14.985
16.185
17.385
18.585
19.785
20.985
22.185
23.385
24.585
25.785
26.985
28.185
29.385
30.585
31.785
32.985
34.185
35.385
36.585
37.785
38.985
40.185
41.385
42.585
43.785
44.985
46.185
47.385
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

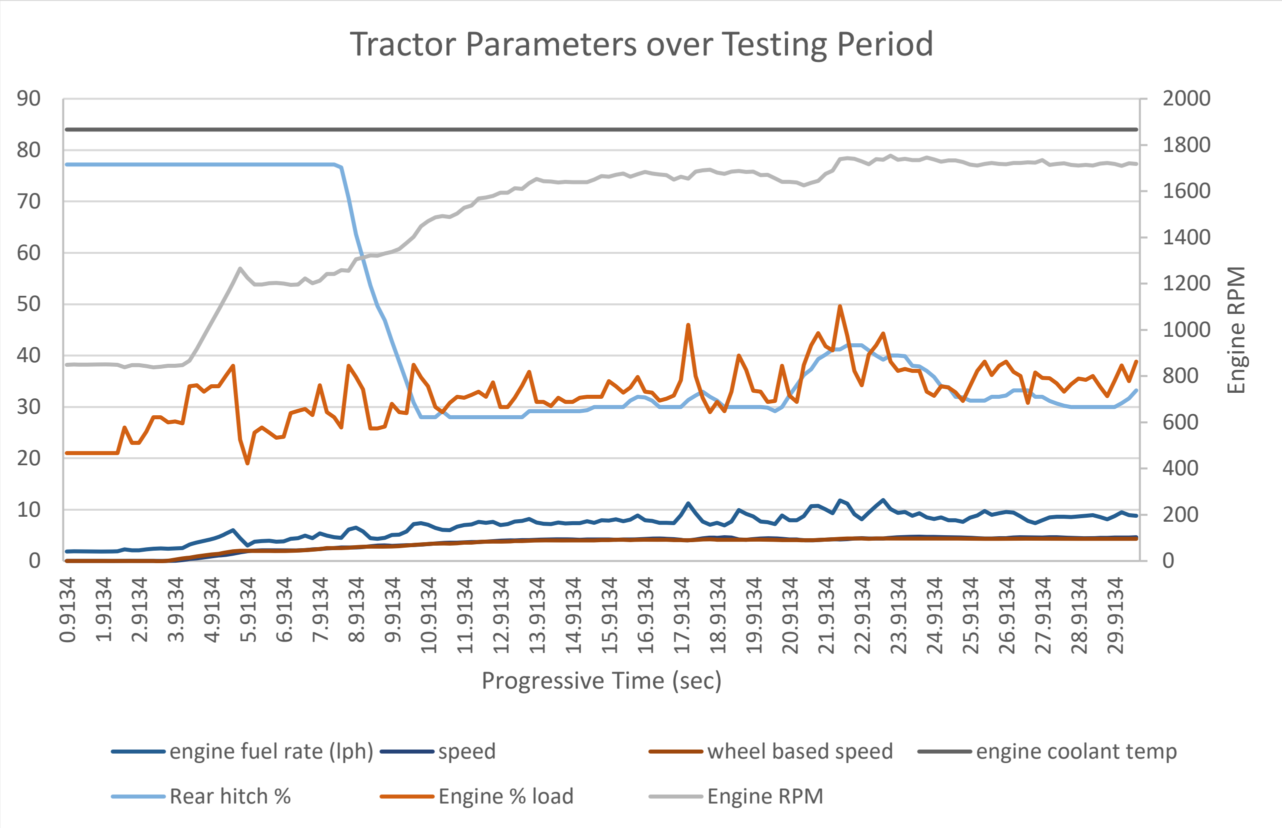

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
1.785
2.985
4.185
5.385
6.585
7.785
8.985
10.185
11.385
12.585
13.785
14.985
16.185
17.385
18.585
19.785
20.985
22.185
23.385
24.585
25.785
26.985
28.185
29.385
30.585
31.785
32.985
34.185
35.385
36.585
37.785
38.985
40.185
41.385
42.585
43.785
44.985
46.185
47.385
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

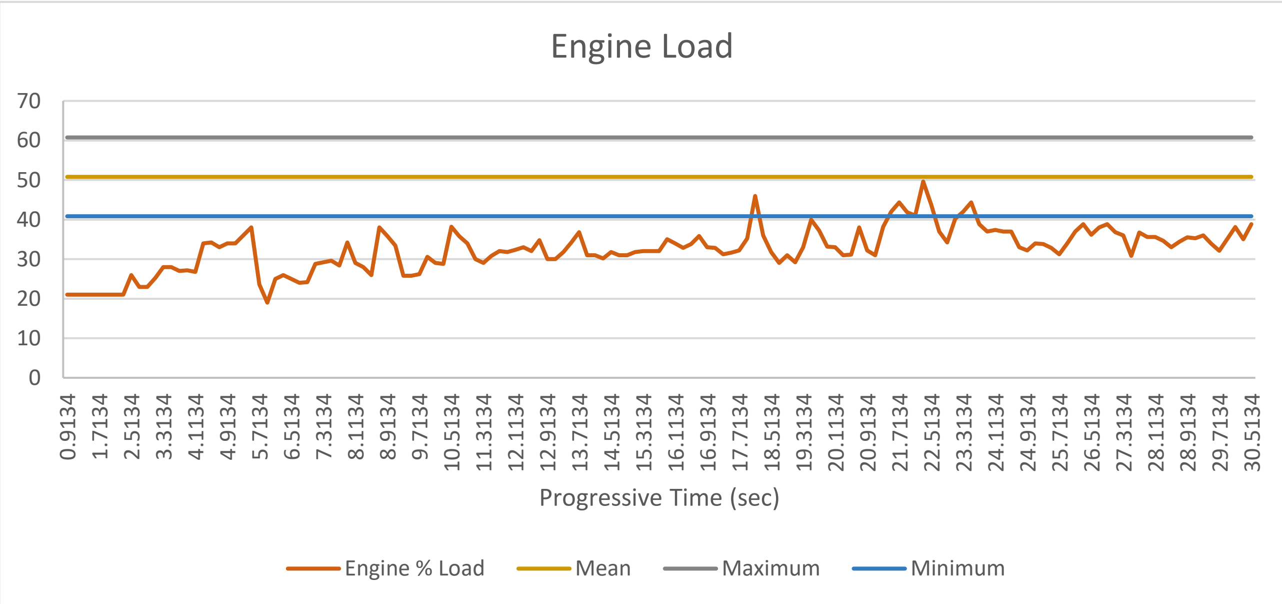

Coolant Temperature
92
90
88
86
84
82
80
78
76
74
1.785 2.985 4.185 5.385 6.585 7.785 8.985 10.185 11.385 12.585 13.785 14.985 16.185 17.385 18.585 19.785 20.985 22.185 23.385 24.585 25.785 26.985 28.185 29.385 30.585 31.785 32.985 34.185 35.385 36.585 37.785 38.985 40.185 41.385 42.585 43.785 44.985 46.185 47.385
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

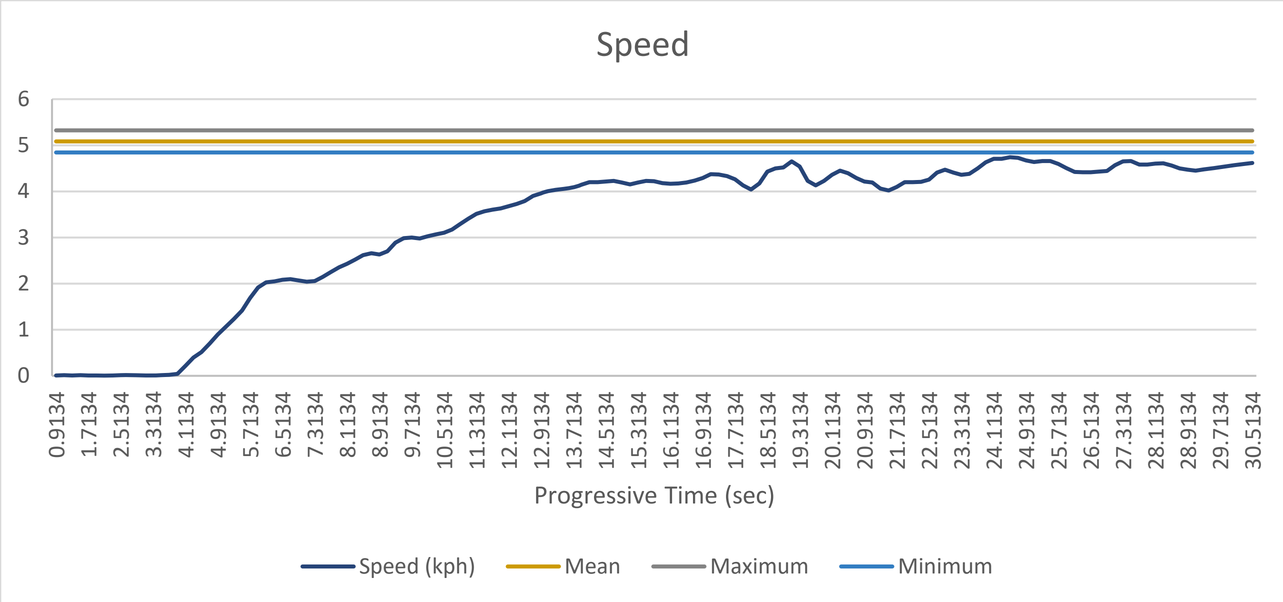

Rear Hitch %
40
35
30
25
20
1.785 2.985 4.185 5.385 6.585 7.785 8.985 10.185 11.385 12.585 13.785 14.985 16.185 17.385 18.585 19.785 20.985 22.185 23.385 24.585 25.785 26.985 28.185 29.385 30.585 31.785 32.985 34.185 35.385 36.585 37.785 38.985 40.185 41.385 42.585 43.785 44.985 46.185 47.385
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

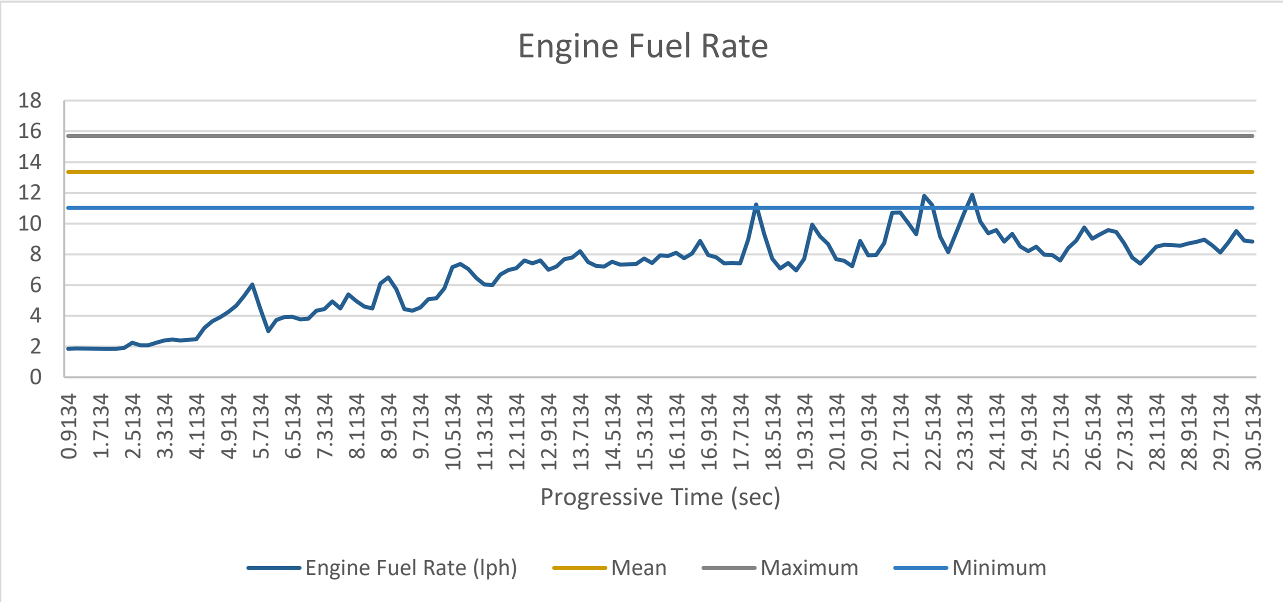

Engine RPM
1915
1910
1905
1900
1895
1890
1885
1880
1875
1870
1.785 2.985 4.185 5.385 6.585 7.785 8.985 10.185 11.385 12.585 13.785 14.985 16.185 17.385 18.585 19.785 20.985 22.185 23.385 24.585 25.785 26.985 28.185 29.385 30.585 31.785 32.985 34.185 35.385 36.585 37.785 38.985 40.185 41.385 42.585 43.785 44.985 46.185 47.385
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

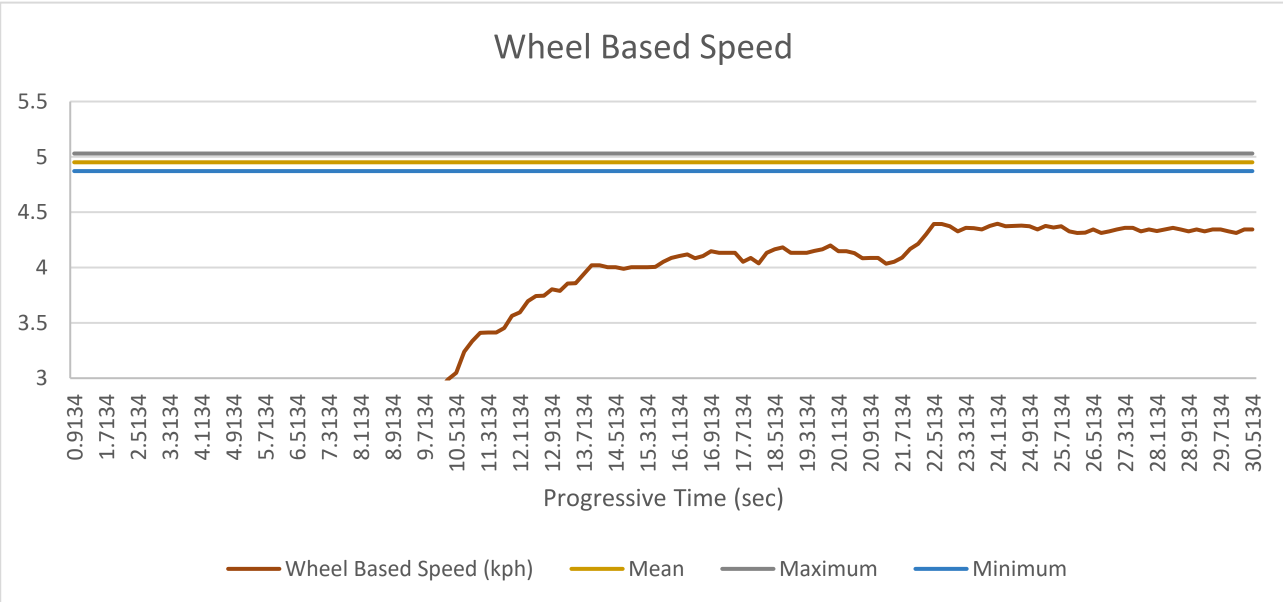
300mm – 5kph

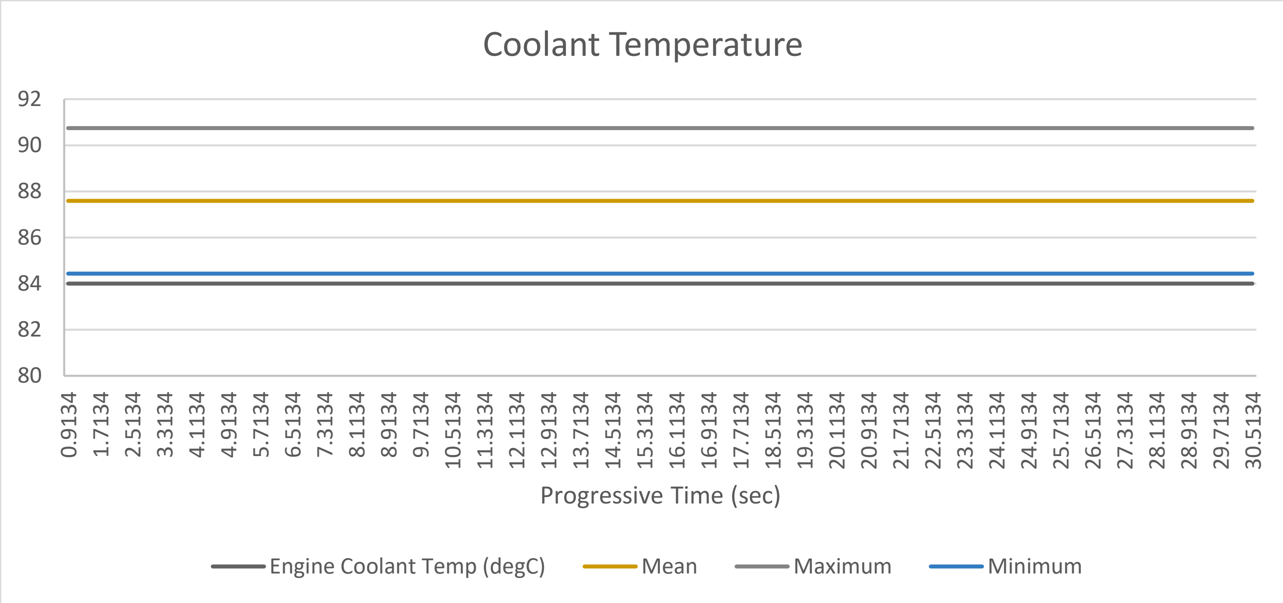

Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Engine RPM
0.9134
1.9134
2.9134
3.9134
4.9134
5.9134
6.9134
7.9134
8.9134
9.9134
10.9134
11.9134
12.9134
13.9134
14.9134
15.9134
16.9134
17.9134
18.9134
19.9134
20.9134
21.9134
22.9134
23.9134
24.9134
25.9134
26.9134
27.9134
28.9134
29.9134
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

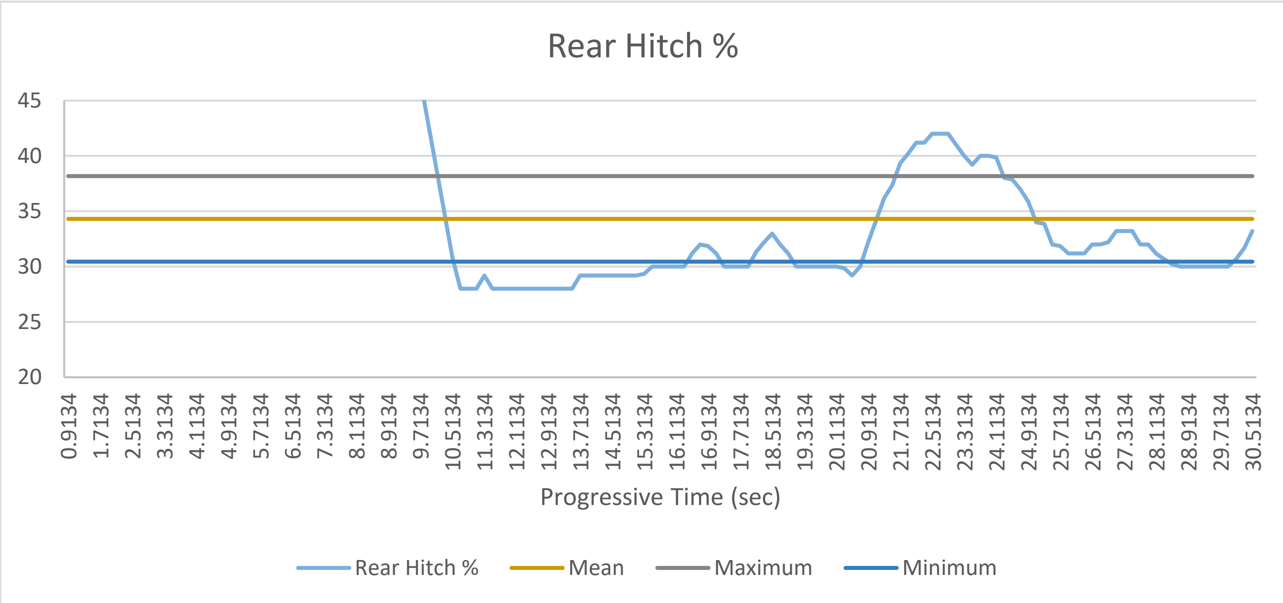

Engine Load
70
60
50
40
30
20
10
0
0.9134
1.7134
2.5134
3.3134
4.1134
4.9134
5.7134
6.5134
7.3134
8.1134
8.9134
9.7134
10.5134
11.3134
12.1134
12.9134
13.7134
14.5134
15.3134
16.1134
16.9134
17.7134
18.5134
19.3134
20.1134
20.9134
21.7134
22.5134
23.3134
24.1134
24.9134
25.7134
26.5134
27.3134
28.1134
28.9134
29.7134
30.5134
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

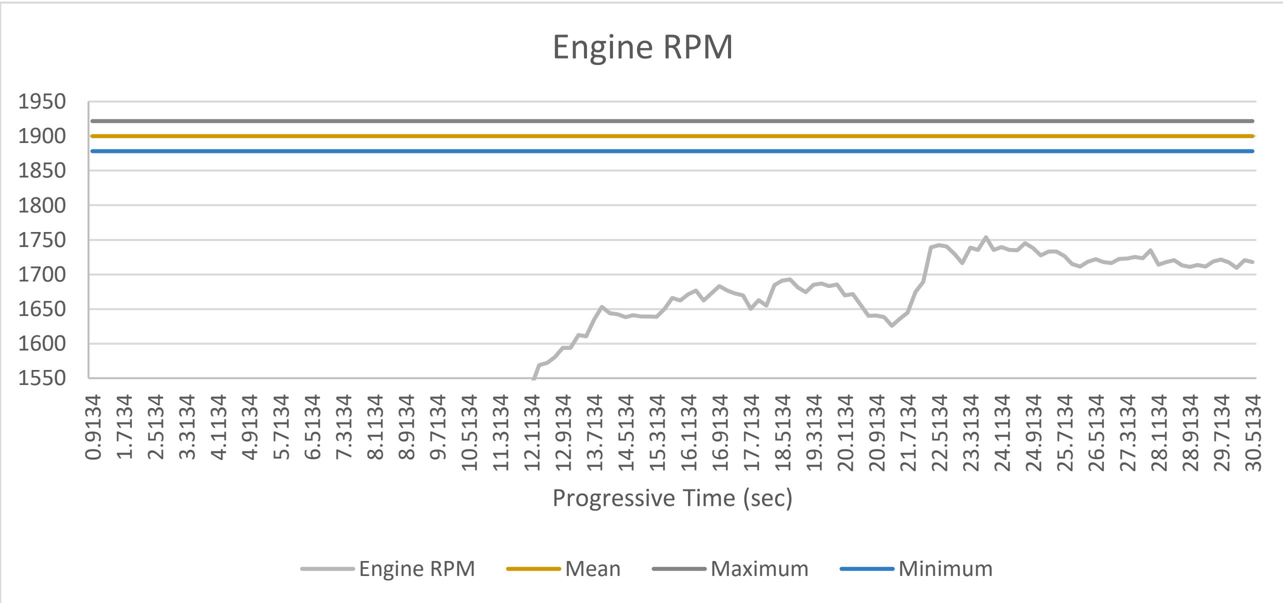

Speed
6
5
4
3
2
1
0
0.9134
1.7134
2.5134
3.3134
4.1134
4.9134
5.7134
6.5134
7.3134
8.1134
8.9134
9.7134
10.5134
11.3134
12.1134
12.9134
13.7134
14.5134
15.3134
16.1134
16.9134
17.7134
18.5134
19.3134
20.1134
20.9134
21.7134
22.5134
23.3134
24.1134
24.9134
25.7134
26.5134
27.3134
28.1134
28.9134
29.7134
30.5134
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
18
16
14
12
10
8
6
4
2
0
0.9134
1.7134
2.5134
3.3134
4.1134
4.9134
5.7134
6.5134
7.3134
8.1134
8.9134
9.7134
10.5134
11.3134
12.1134
12.9134
13.7134
14.5134
15.3134
16.1134
16.9134
17.7134
18.5134
19.3134
20.1134
20.9134
21.7134
22.5134
23.3134
24.1134
24.9134
25.7134
26.5134
27.3134
28.1134
28.9134
29.7134
30.5134
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

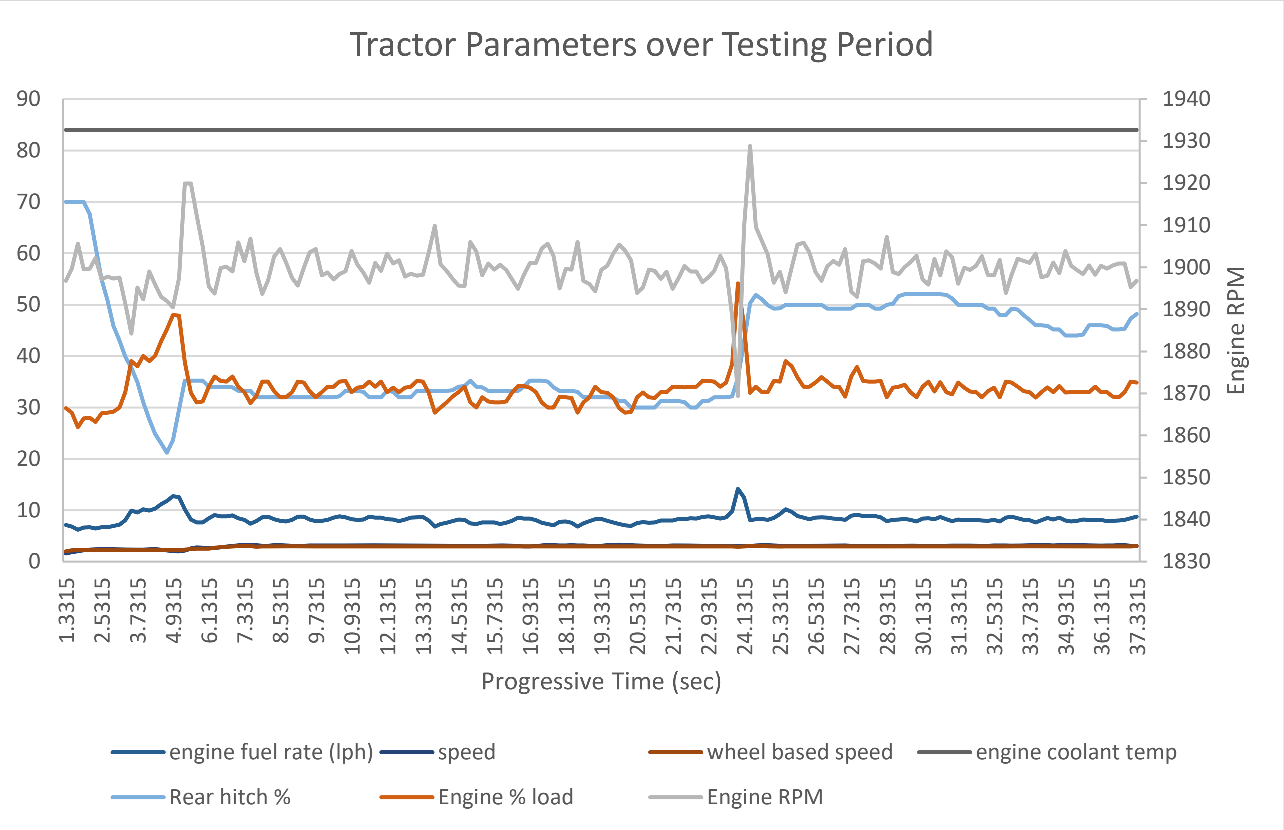

Wheel Based Speed
5.5
5
4.5
4
3.5
3
0.9134
1.7134
2.5134
3.3134
4.1134
4.9134
5.7134
6.5134
7.3134
8.1134
8.9134
9.7134
10.5134
11.3134
12.1134
12.9134
13.7134
14.5134
15.3134
16.1134
16.9134
17.7134
18.5134
19.3134
20.1134
20.9134
21.7134
22.5134
23.3134
24.1134
24.9134
25.7134
26.5134
27.3134
28.1134
28.9134
29.7134
30.5134
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

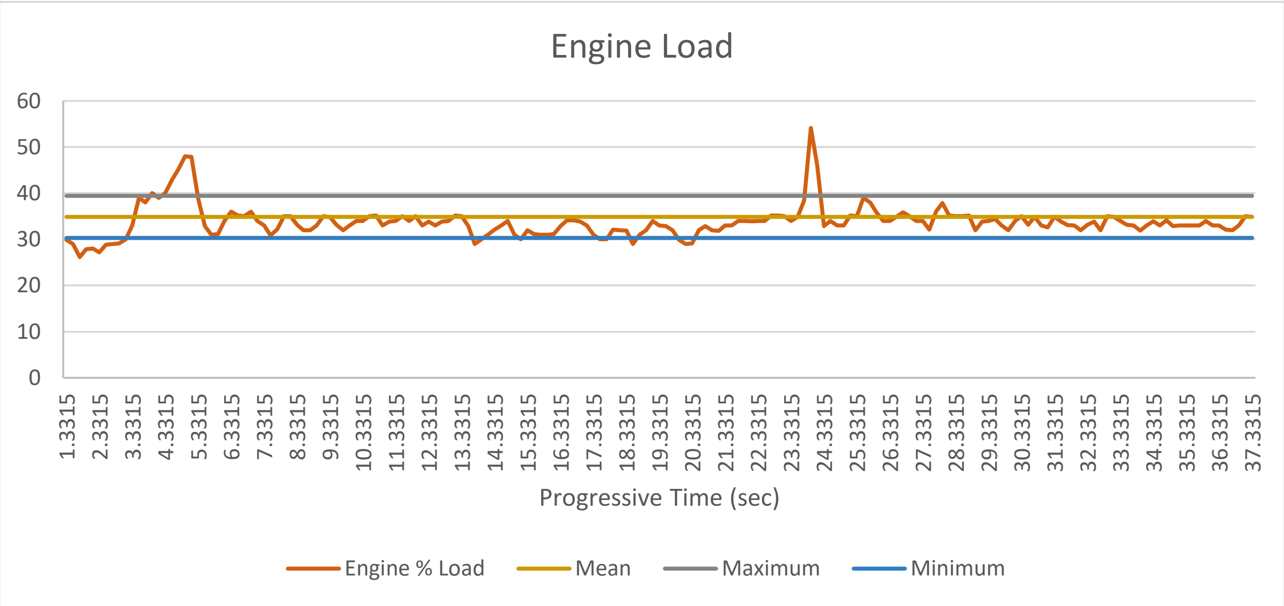

Coolant Temperature
92
90
88
86
84
82
80
0.9134 1.7134 2.5134 3.3134 4.1134 4.9134 5.7134 6.5134 7.3134 8.1134 8.9134 9.7134 10.5134 11.3134 12.1134 12.9134 13.7134 14.5134 15.3134 16.1134 16.9134 17.7134 18.5134 19.3134 20.1134 20.9134 21.7134 22.5134 23.3134 24.1134 24.9134 25.7134 26.5134 27.3134 28.1134 28.9134 29.7134 30.5134
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

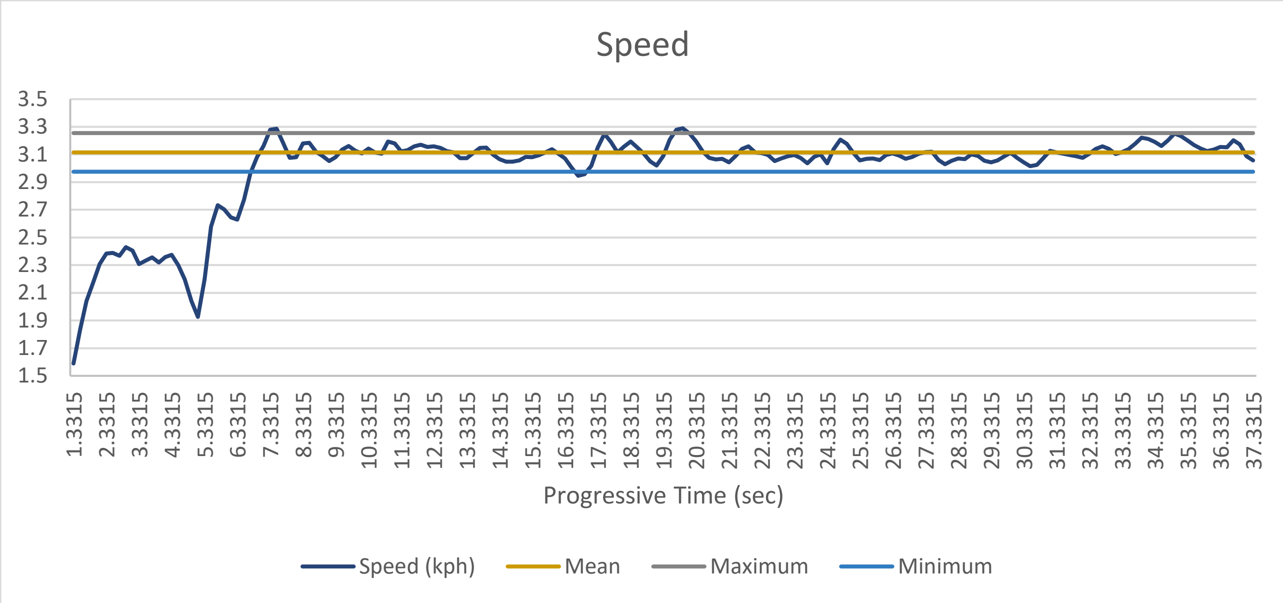

Rear Hitch %
45
40
35
30
25
20
0.9134 1.7134 2.5134 3.3134 4.1134 4.9134 5.7134 6.5134 7.3134 8.1134 8.9134 9.7134 10.5134 11.3134 12.1134 12.9134 13.7134 14.5134 15.3134 16.1134 16.9134 17.7134 18.5134 19.3134 20.1134 20.9134 21.7134 22.5134 23.3134 24.1134 24.9134 25.7134 26.5134 27.3134 28.1134 28.9134 29.7134 30.5134
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

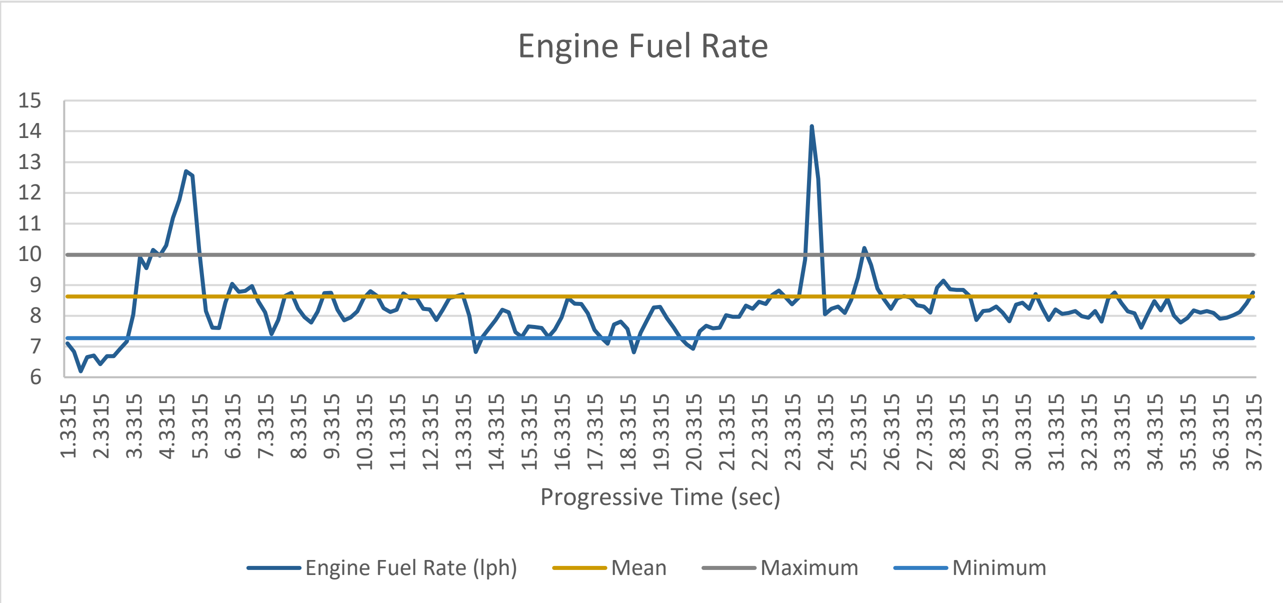

Engine RPM
1950
1900
1850
1800
1750
1700
1650
1600
1550
0.9134 1.7134 2.5134 3.3134 4.1134 4.9134 5.7134 6.5134 7.3134 8.1134 8.9134 9.7134 10.5134 11.3134 12.1134 12.9134 13.7134 14.5134 15.3134 16.1134 16.9134 17.7134 18.5134 19.3134 20.1134 20.9134 21.7134 22.5134 23.3134 24.1134 24.9134 25.7134 26.5134 27.3134 28.1134 28.9134 29.7134 30.5134
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

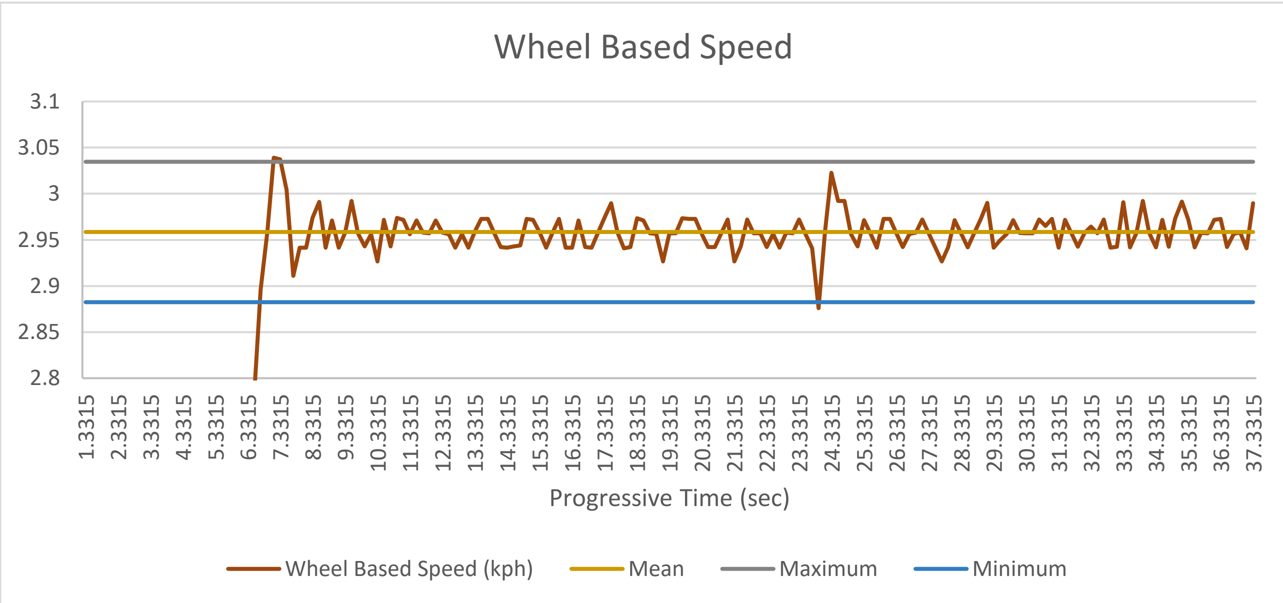
200mm – 3kph

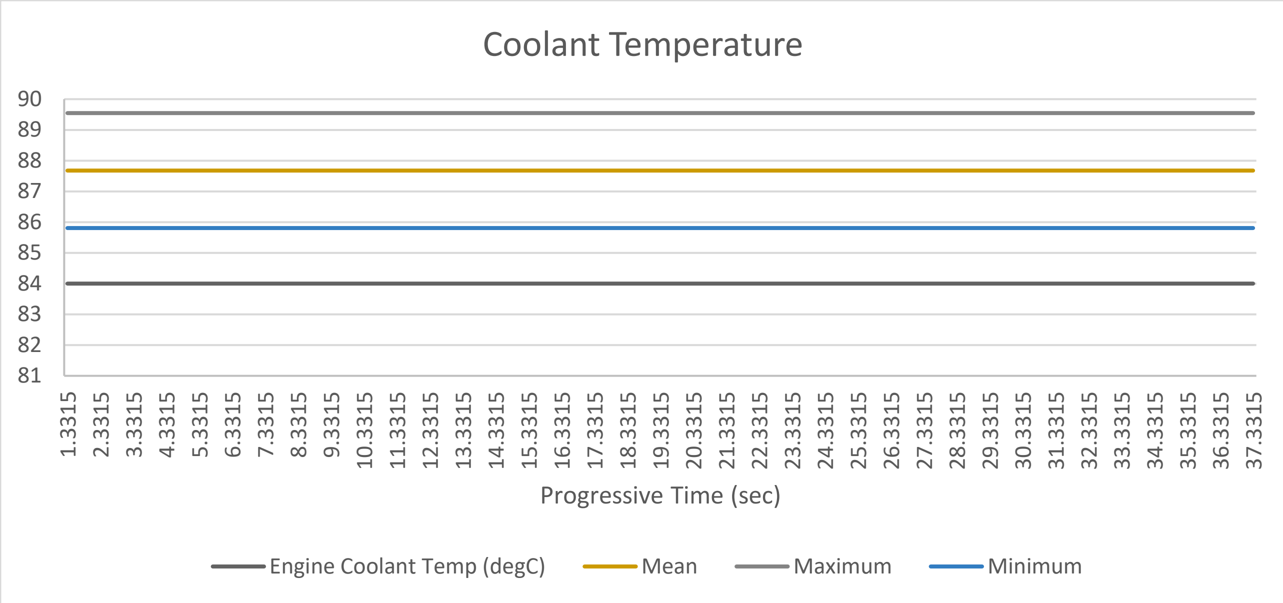

Tractor Parameters over Testing Period
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

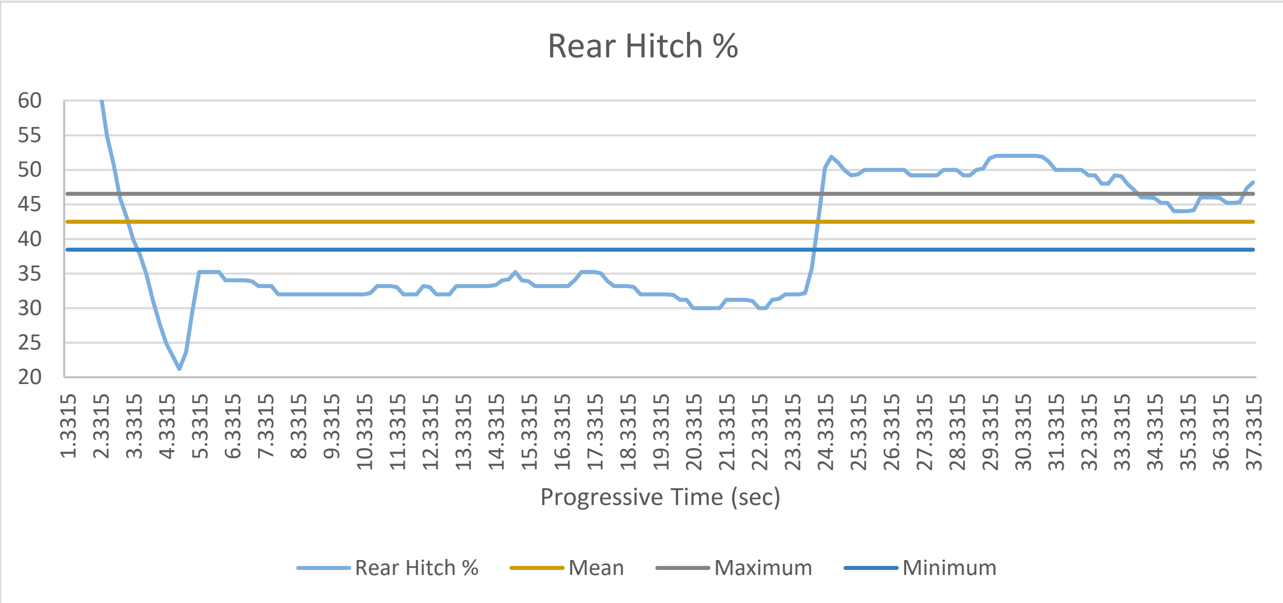

Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

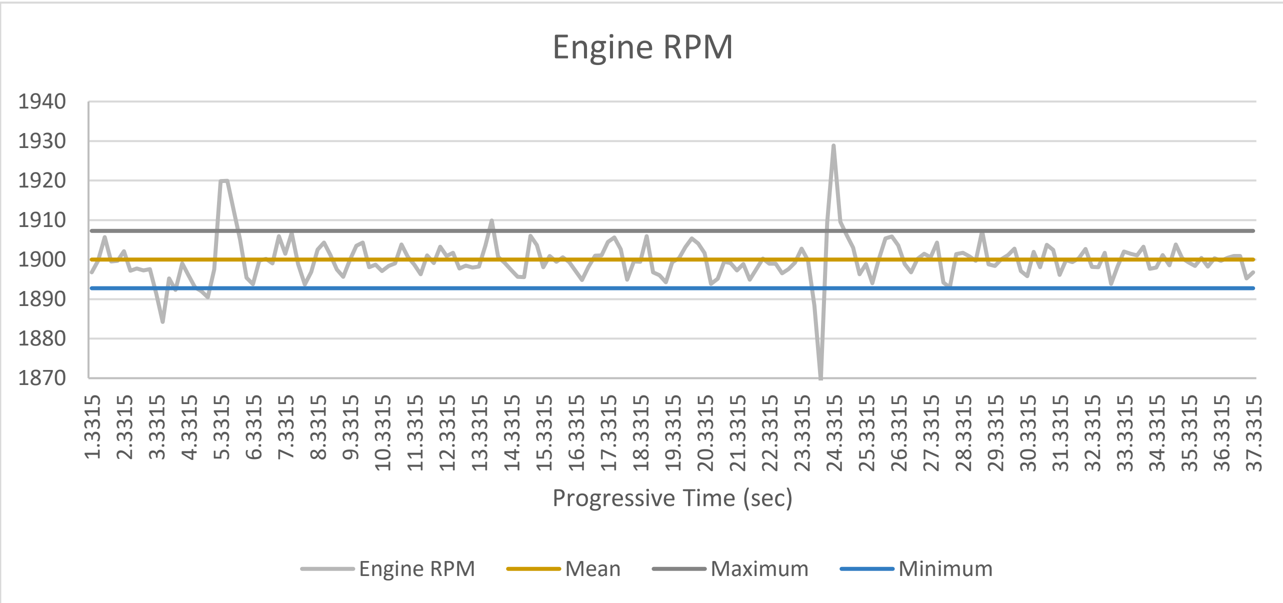

Speed
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
1.3315 2.3315 3.3315 4.3315 5.3315 6.3315 7.3315 8.3315 9.3315 10.3315 11.3315 12.3315 13.3315 14.3315 15.3315 16.3315 17.3315 18.3315 19.3315 20.3315 21.3315 22.3315 23.3315 24.3315 25.3315 26.3315 27.3315 28.3315 29.3315 30.3315 31.3315 32.3315 33.3315 34.3315 35.3315 36.3315 37.3315
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
15
14
13
12
11
10
9
8
7
6
1.3315 2.3315 3.3315 4.3315 5.3315 6.3315 7.3315 8.3315 9.3315 10.3315 11.3315 12.3315 13.3315 14.3315 15.3315 16.3315 17.3315 18.3315 19.3315 20.3315 21.3315 22.3315 23.3315 24.3315 25.3315 26.3315 27.3315 28.3315 29.3315 30.3315 31.3315 32.3315 33.3315 34.3315 35.3315 36.3315 37.3315
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

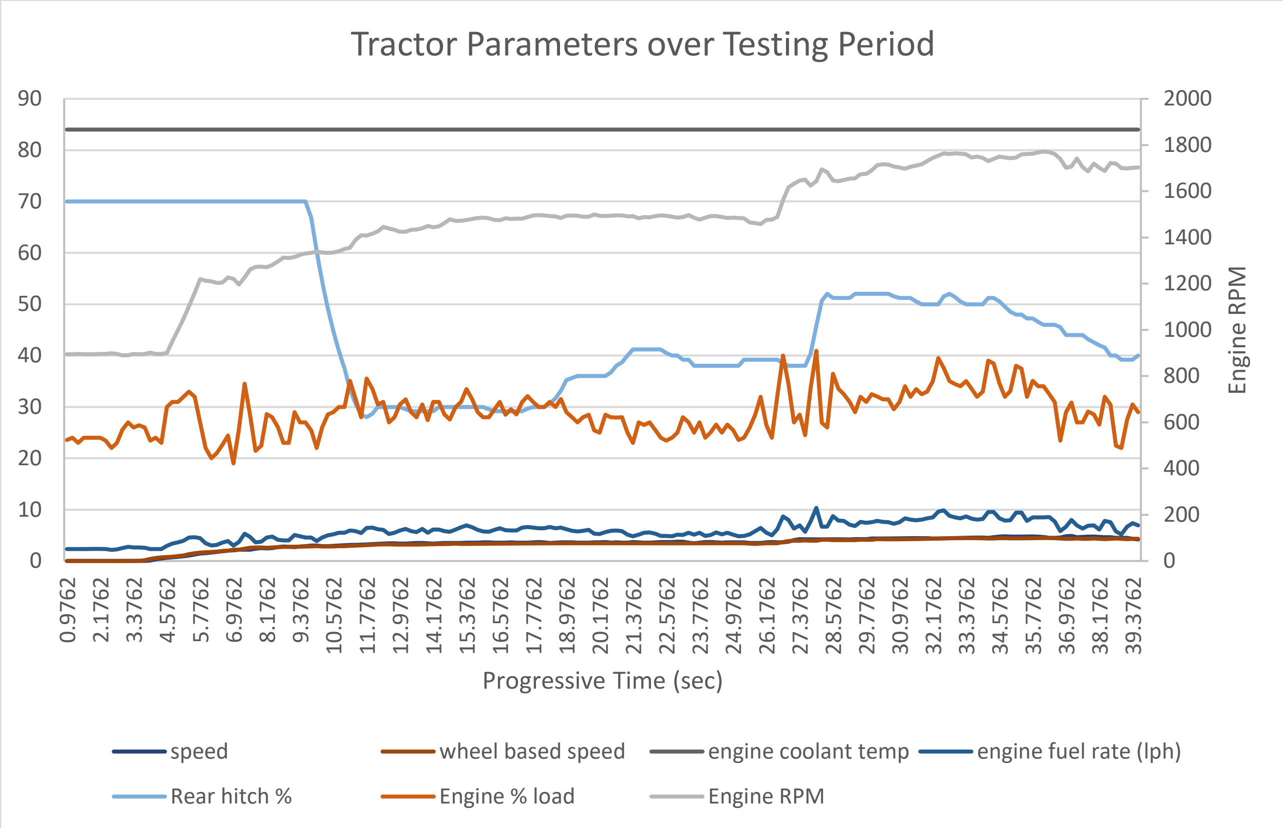

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
1.3315 2.3315 3.3315 4.3315 5.3315 6.3315 7.3315 8.3315 9.3315 10.3315 11.3315 12.3315 13.3315 14.3315 15.3315 16.3315 17.3315 18.3315 19.3315 20.3315 21.3315 22.3315 23.3315 24.3315 25.3315 26.3315 27.3315 28.3315 29.3315 30.3315 31.3315 32.3315 33.3315 34.3315 35.3315 36.3315 37.3315
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
89
88
87
86
85
84
83
82
81
1.3315
2.3315
3.3315
4.3315
5.3315
6.3315
7.3315
8.3315
9.3315
10.3315
11.3315
12.3315
13.3315
14.3315
15.3315
16.3315
17.3315
18.3315
19.3315
20.3315
21.3315
22.3315
23.3315
24.3315
25.3315
26.3315
27.3315
28.3315
29.3315
30.3315
31.3315
32.3315
33.3315
34.3315
35.3315
36.3315
37.3315
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

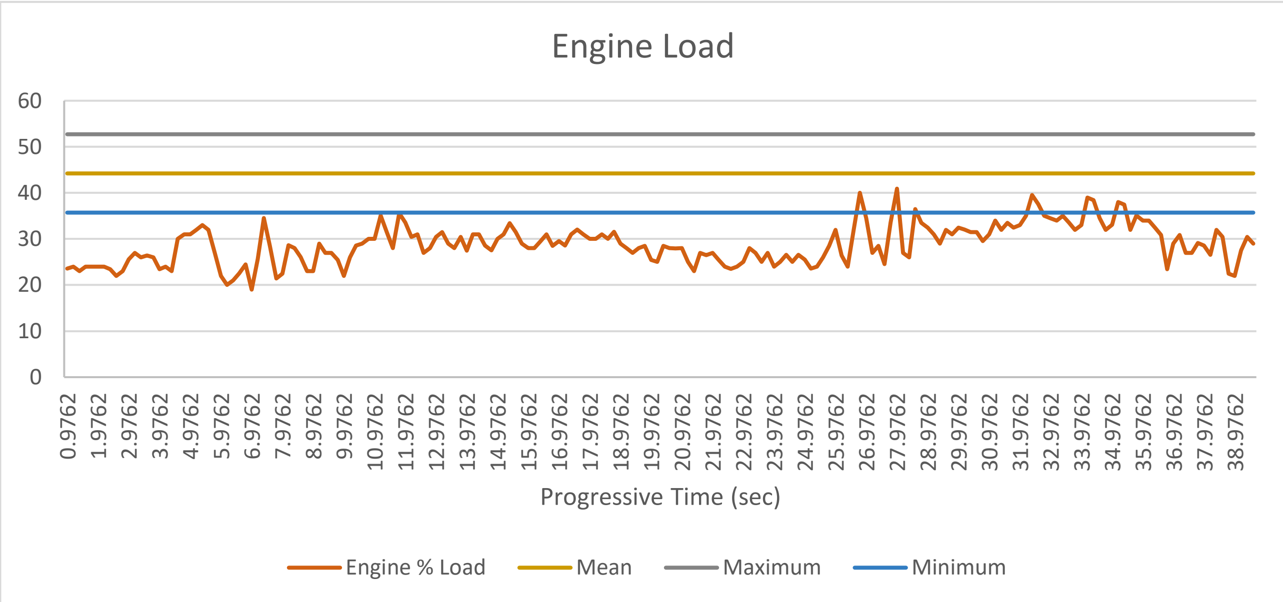

Rear Hitch %
60
55
50
45
40
35
30
25
20
1.3315
2.3315
3.3315
4.3315
5.3315
6.3315
7.3315
8.3315
9.3315
10.3315
11.3315
12.3315
13.3315
14.3315
15.3315
16.3315
17.3315
18.3315
19.3315
20.3315
21.3315
22.3315
23.3315
24.3315
25.3315
26.3315
27.3315
28.3315
29.3315
30.3315
31.3315
32.3315
33.3315
34.3315
35.3315
36.3315
37.3315
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1.3315
2.3315
3.3315
4.3315
5.3315
6.3315
7.3315
8.3315
9.3315
10.3315
11.3315
12.3315
13.3315
14.3315
15.3315
16.3315
17.3315
18.3315
19.3315
20.3315
21.3315
22.3315
23.3315
24.3315
25.3315
26.3315
27.3315
28.3315
29.3315
30.3315
31.3315
32.3315
33.3315
34.3315
35.3315
36.3315
37.3315
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

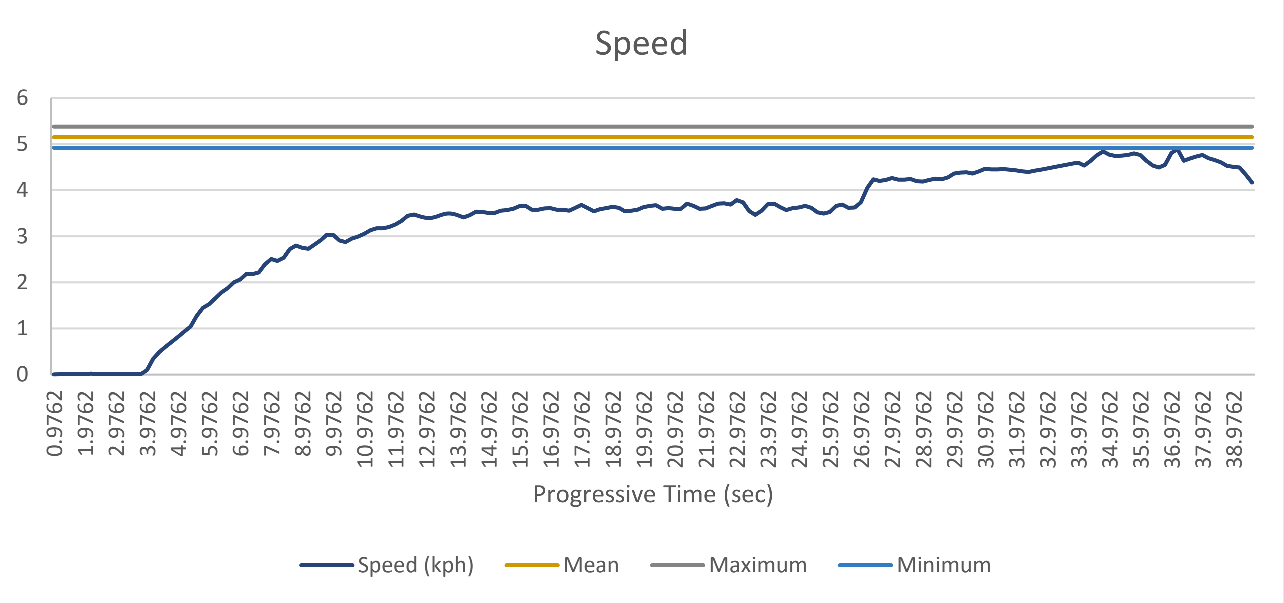
200mm – 5kph

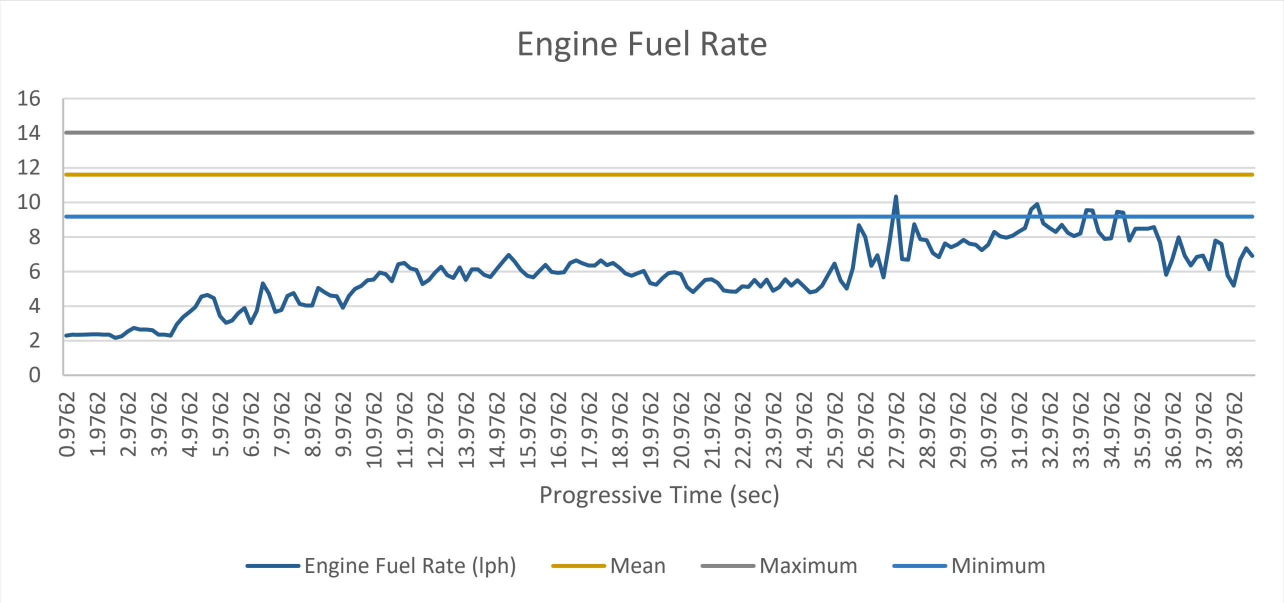


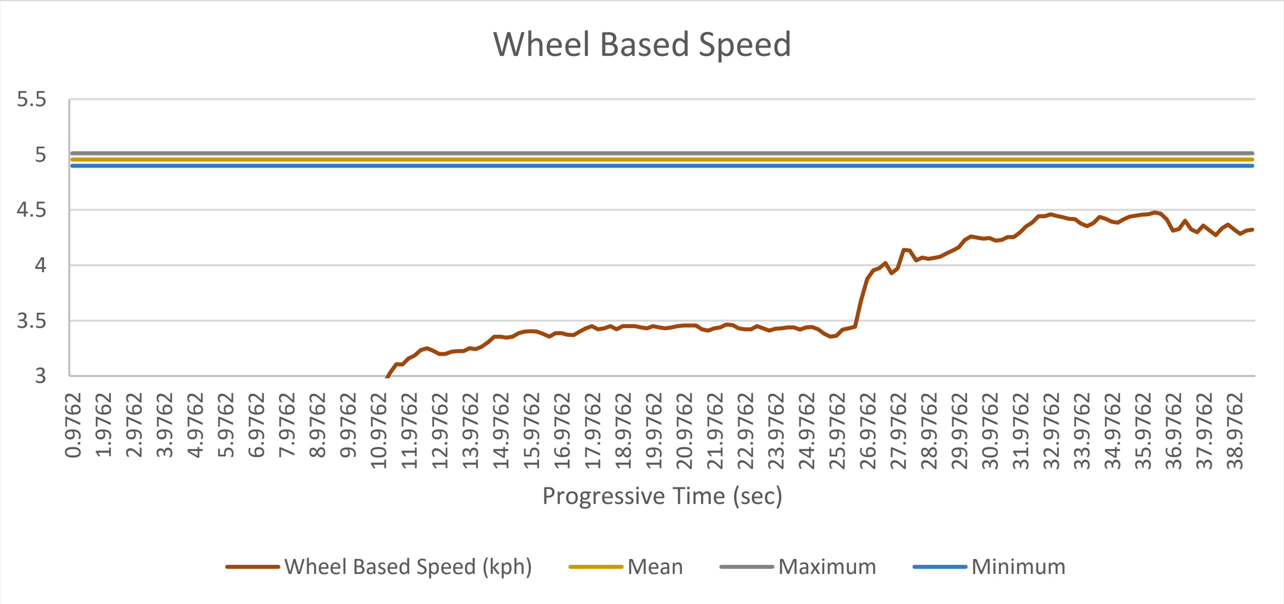
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Engine RPM
0.9762
2.1762
3.3762
4.5762
5.7762
6.9762
8.1762
9.3762
10.5762
11.7762
12.9762
14.1762
15.3762
16.5762
17.7762
18.9762
20.1762
21.3762
22.5762
23.7762
24.9762
26.1762
27.3762
28.5762
29.7762
30.9762
32.1762
33.3762
34.5762
35.7762
36.9762
38.1762
39.3762
Progressive Time (sec)
speed
wheel based speed
engine coolant temp
engine fuel rate (lph)
Rear hitch %
Engine % load
Engine RPM

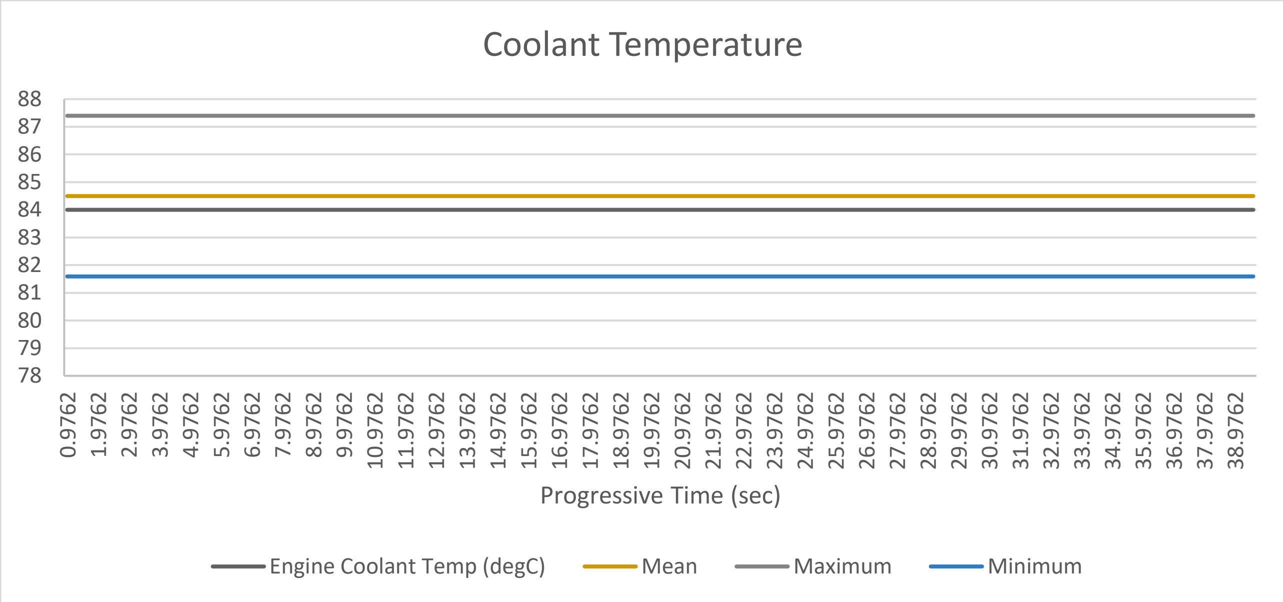


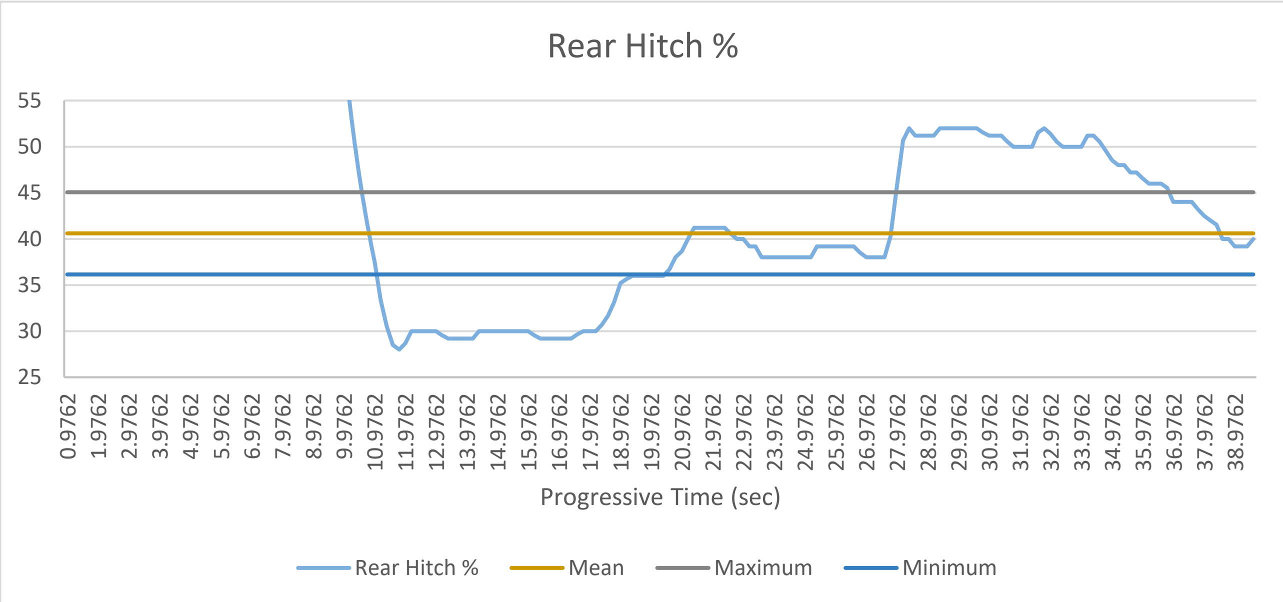
Engine Load
60
50
40
30
20
10
0
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

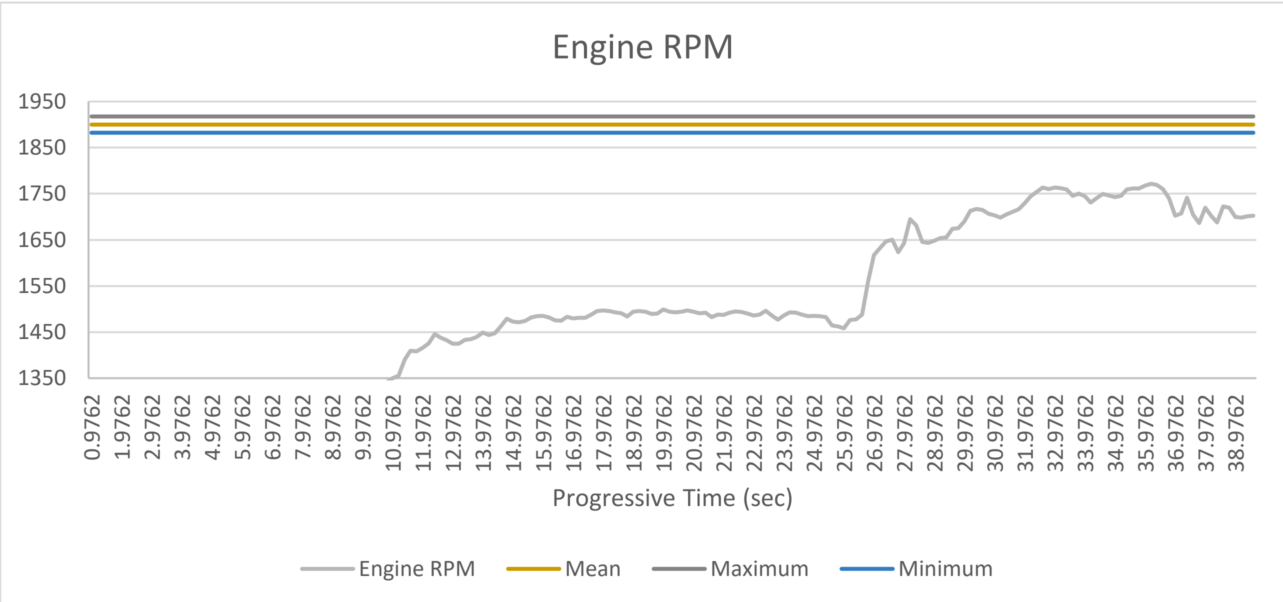

Speed
6
5
4
3
2
1
0
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
16
14
12
10
8
6
4
2
0
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
5.5
5
4.5
4
3.5
3
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

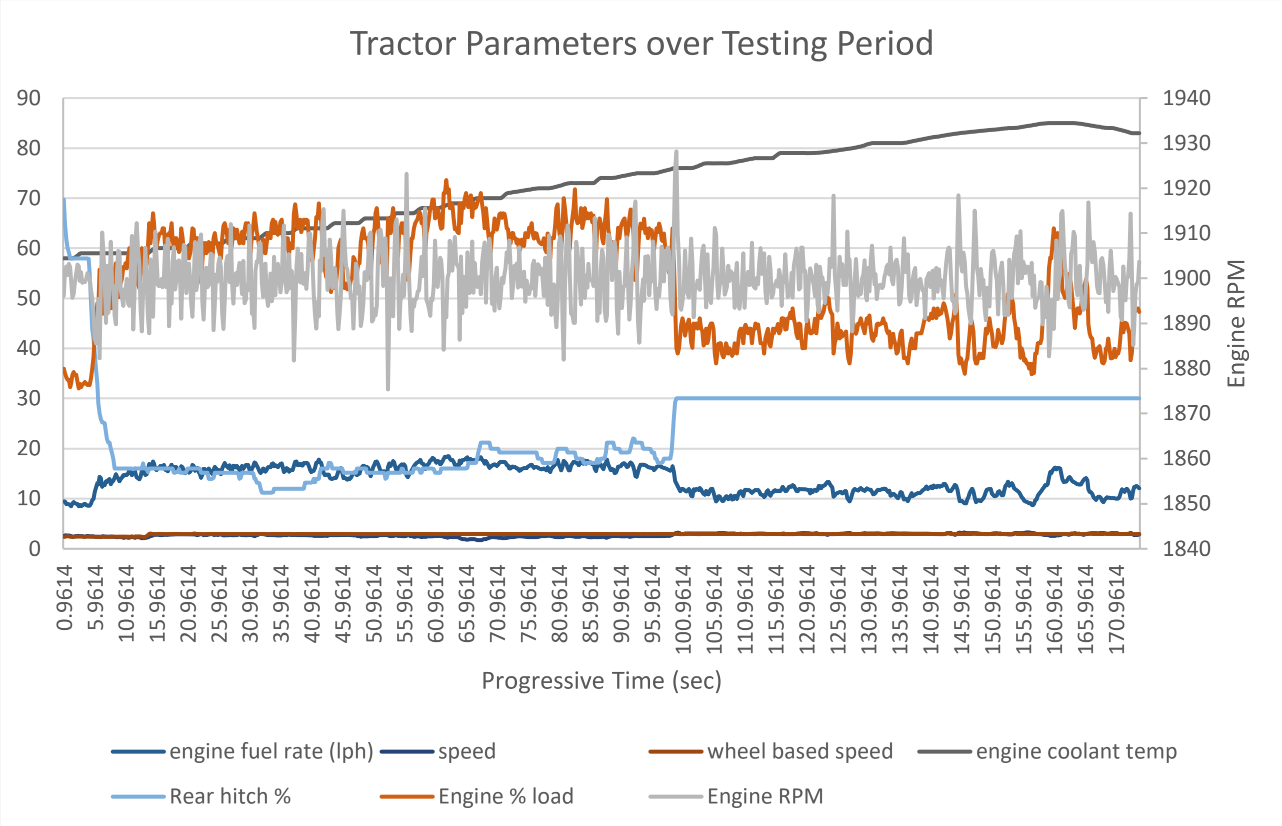

Coolant Temperature
88
87
86
85
84
83
82
81
80
79
78
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

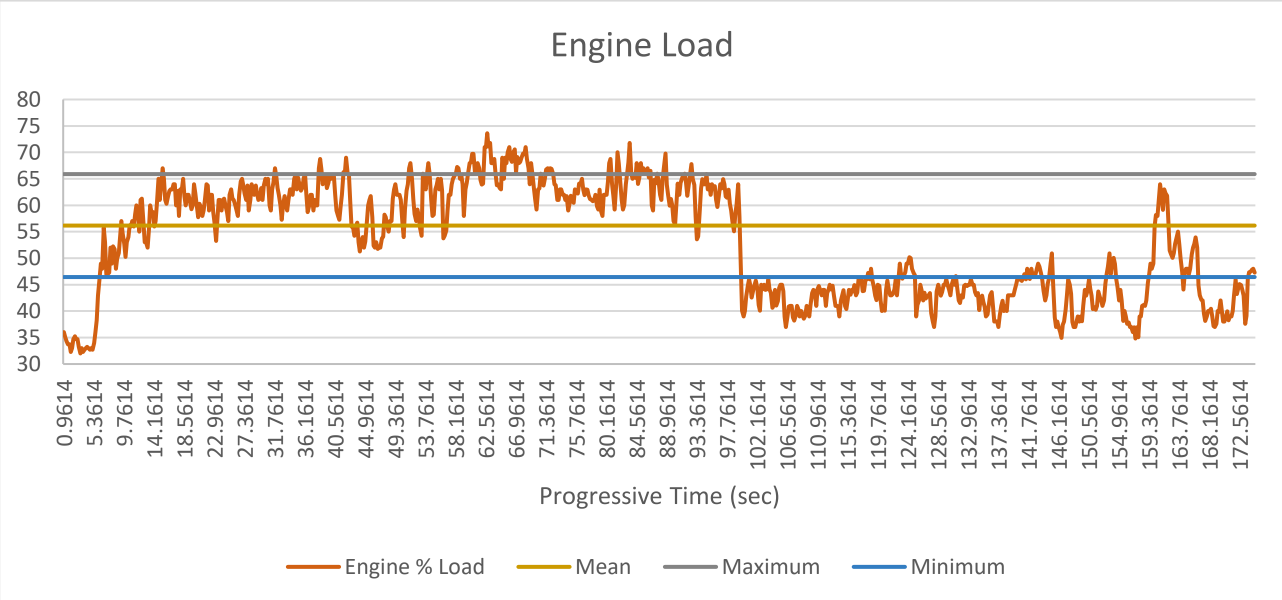

Rear Hitch %
55
50
45
40
35
30
25
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

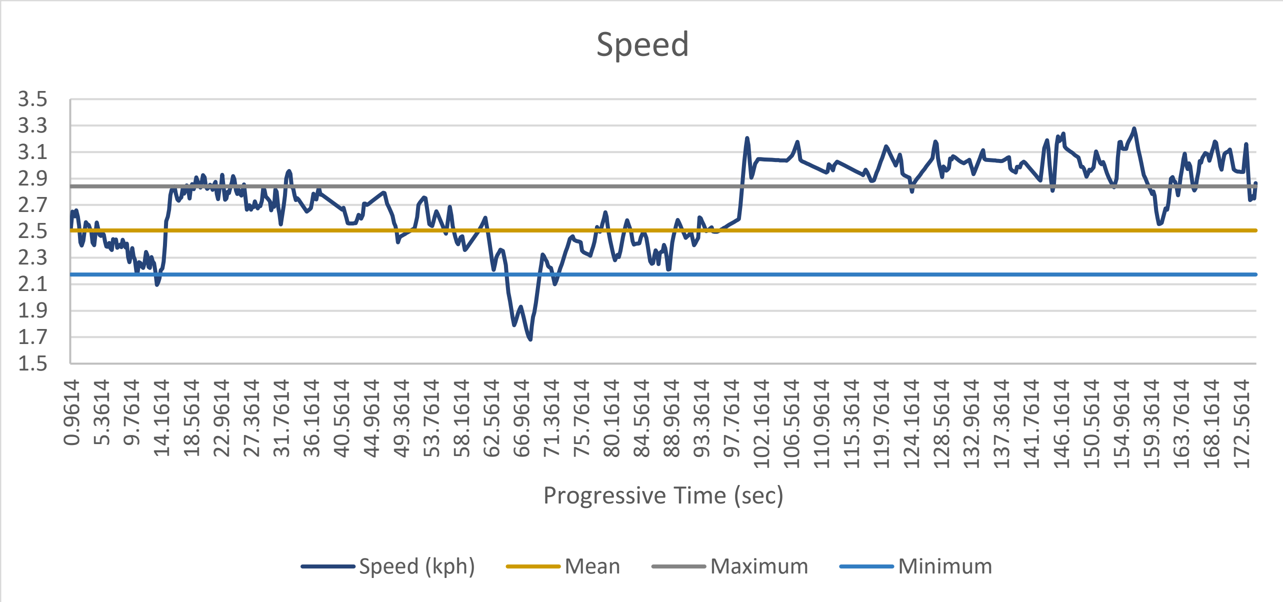

Engine RPM
1950
1850
1750
1650
1550
1450
1350
0.9762
1.9762
2.9762
3.9762
4.9762
5.9762
6.9762
7.9762
8.9762
9.9762
10.9762
11.9762
12.9762
13.9762
14.9762
15.9762
16.9762
17.9762
18.9762
19.9762
20.9762
21.9762
22.9762
23.9762
24.9762
25.9762
26.9762
27.9762
28.9762
29.9762
30.9762
31.9762
32.9762
33.9762
34.9762
35.9762
36.9762
37.9762
38.9762
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

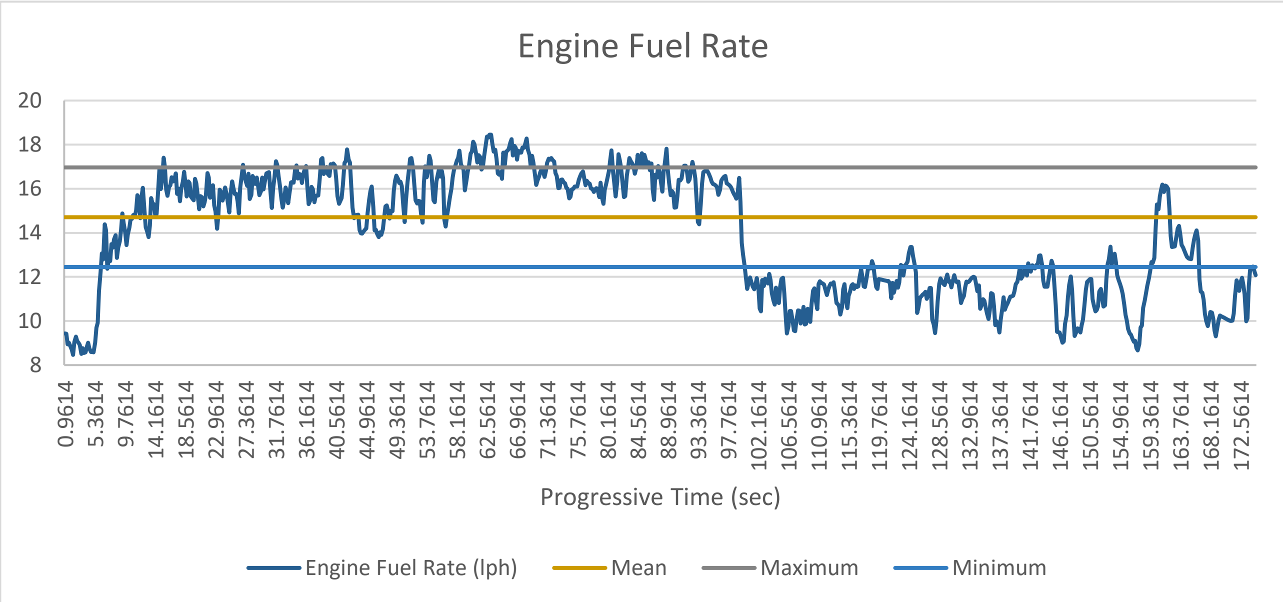
Appendix J – 3PL Deep Ripper – Ripper not digging in far enough data

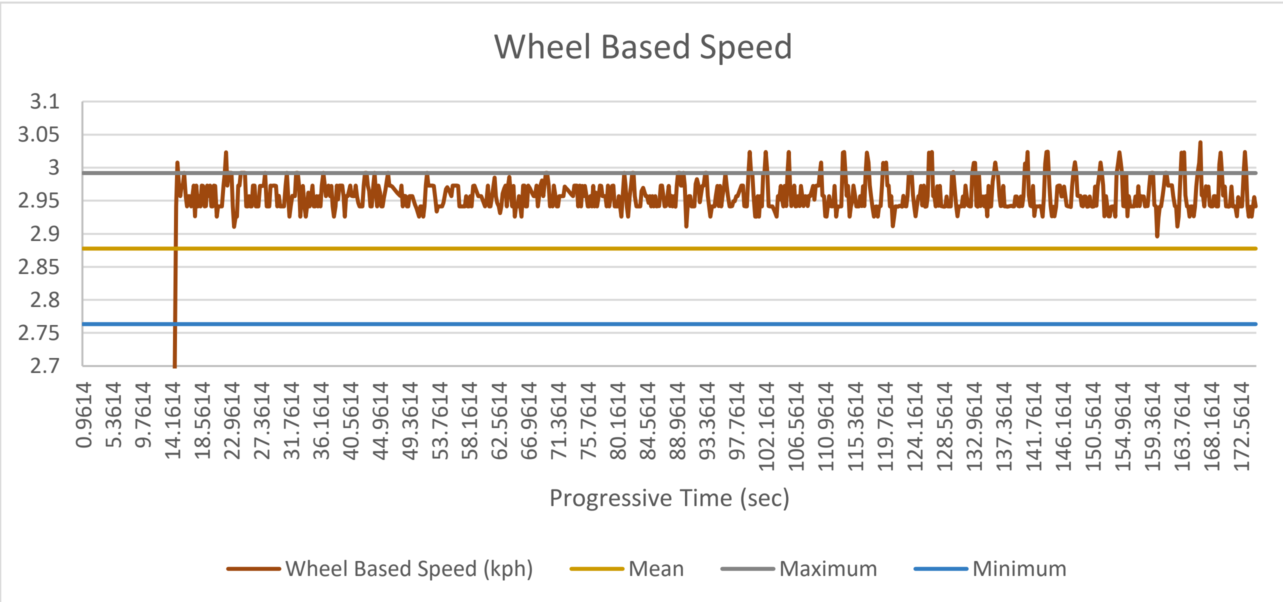
350mm – 3kph

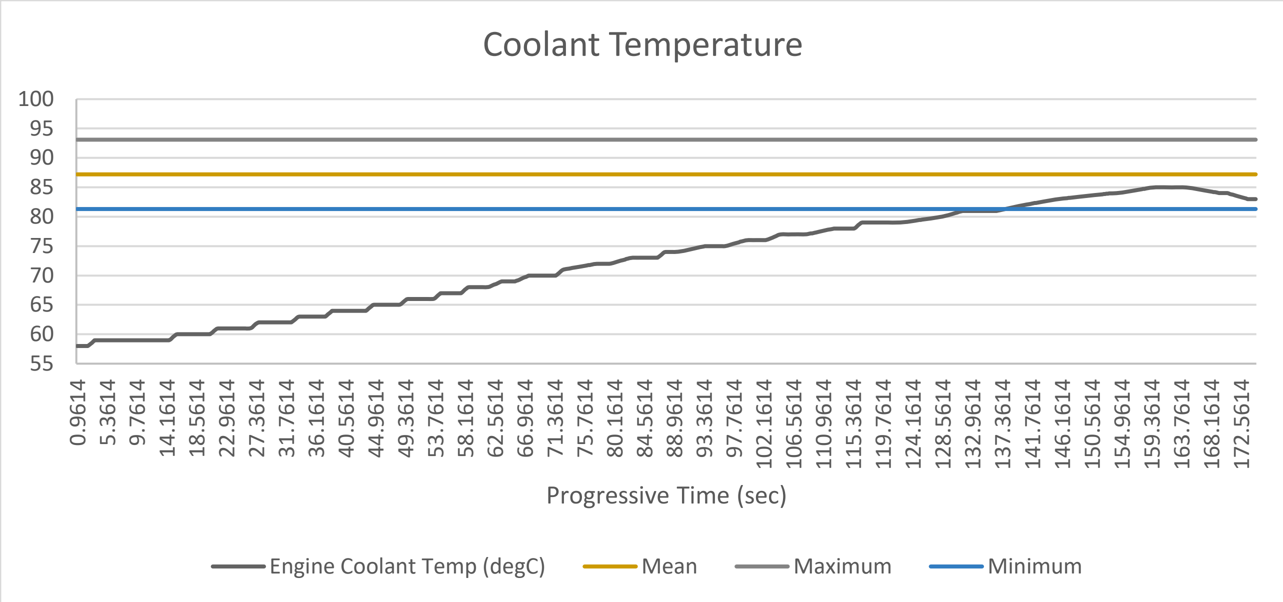


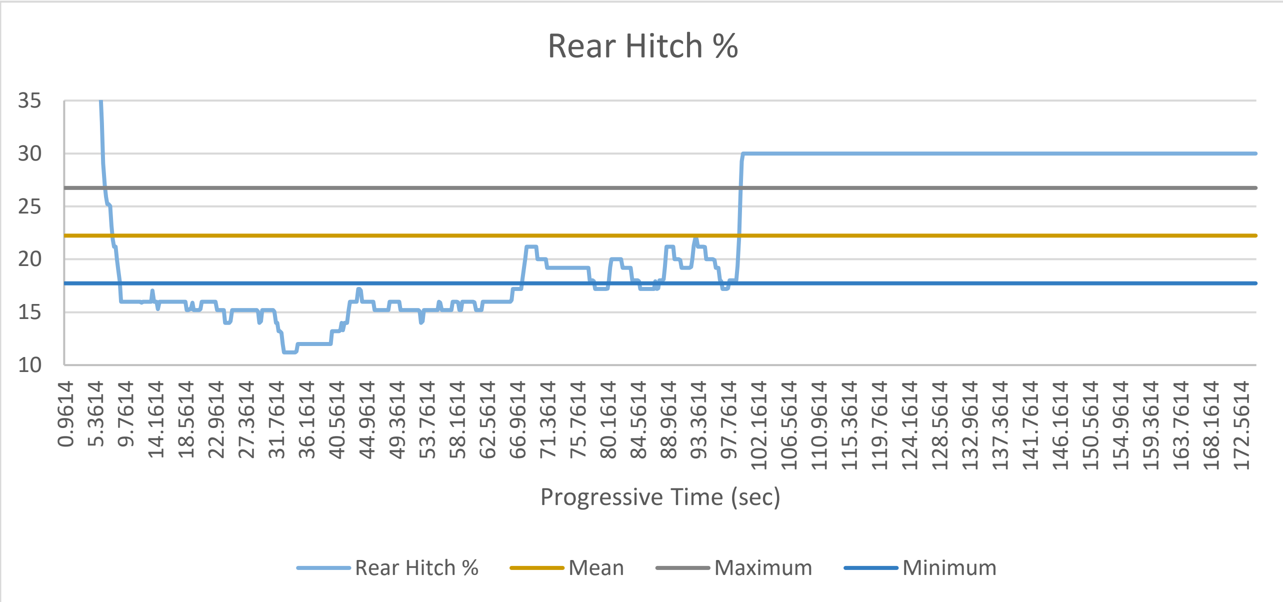


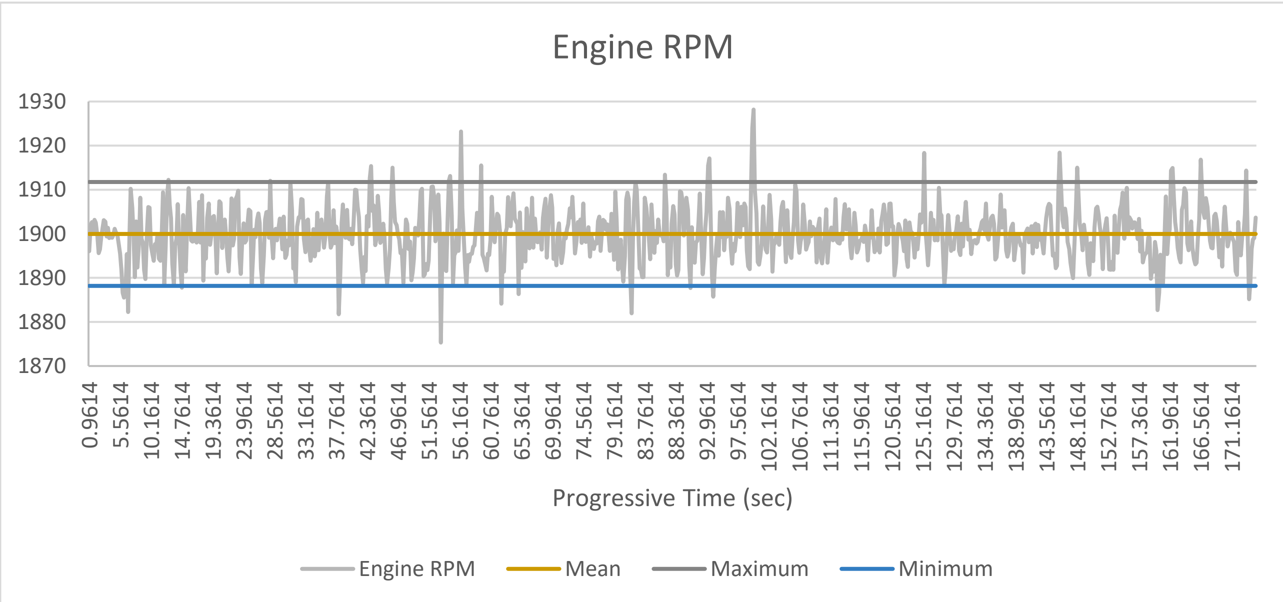

Speed
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
0.9614
5.3614
9.7614
14.1614
18.5614
22.9614
27.3614
31.7614
36.1614
40.5614
44.9614
49.3614
53.7614
58.1614
62.5614
66.9614
71.3614
75.7614
80.1614
84.5614
88.9614
93.3614
97.7614
102.1614
106.5614
110.9614
115.3614
119.7614
124.1614
128.5614
132.9614
137.3614
141.7614
146.1614
150.5614
154.9614
159.3614
163.7614
168.1614
172.5614
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
20
18
16
14
12
10
8
0.9614
5.3614
9.7614
14.1614
18.5614
22.9614
27.3614
31.7614
36.1614
40.5614
44.9614
49.3614
53.7614
58.1614
62.5614
66.9614
71.3614
75.7614
80.1614
84.5614
88.9614
93.3614
97.7614
102.1614
106.5614
110.9614
115.3614
119.7614
124.1614
128.5614
132.9614
137.3614
141.7614
146.1614
150.5614
154.9614
159.3614
163.7614
168.1614
172.5614
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

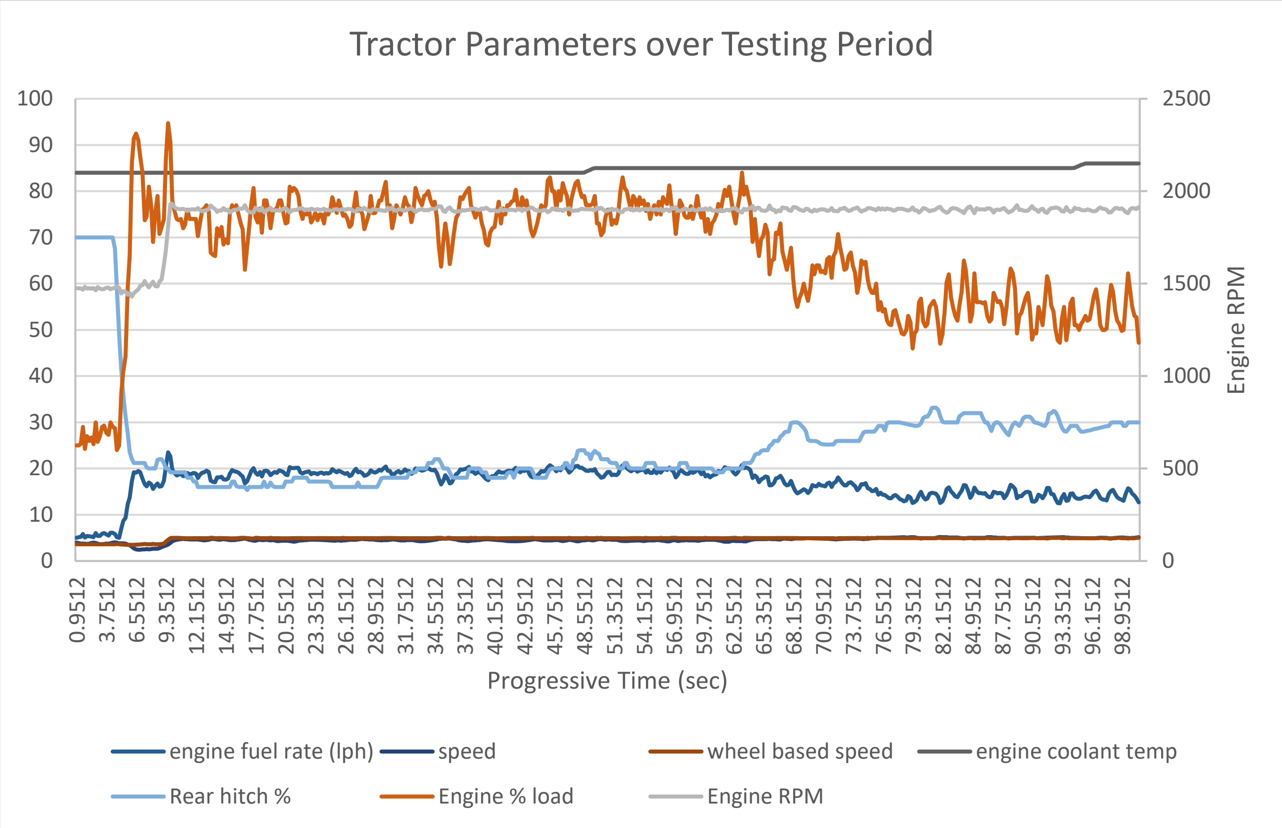

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
0.9614
5.3614
9.7614
14.1614
18.5614
22.9614
27.3614
31.7614
36.1614
40.5614
44.9614
49.3614
53.7614
58.1614
62.5614
66.9614
71.3614
75.7614
80.1614
84.5614
88.9614
93.3614
97.7614
102.1614
106.5614
110.9614
115.3614
119.7614
124.1614
128.5614
132.9614
137.3614
141.7614
146.1614
150.5614
154.9614
159.3614
163.7614
168.1614
172.5614
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
100
95
90
85
80
75
70
65
60
55
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

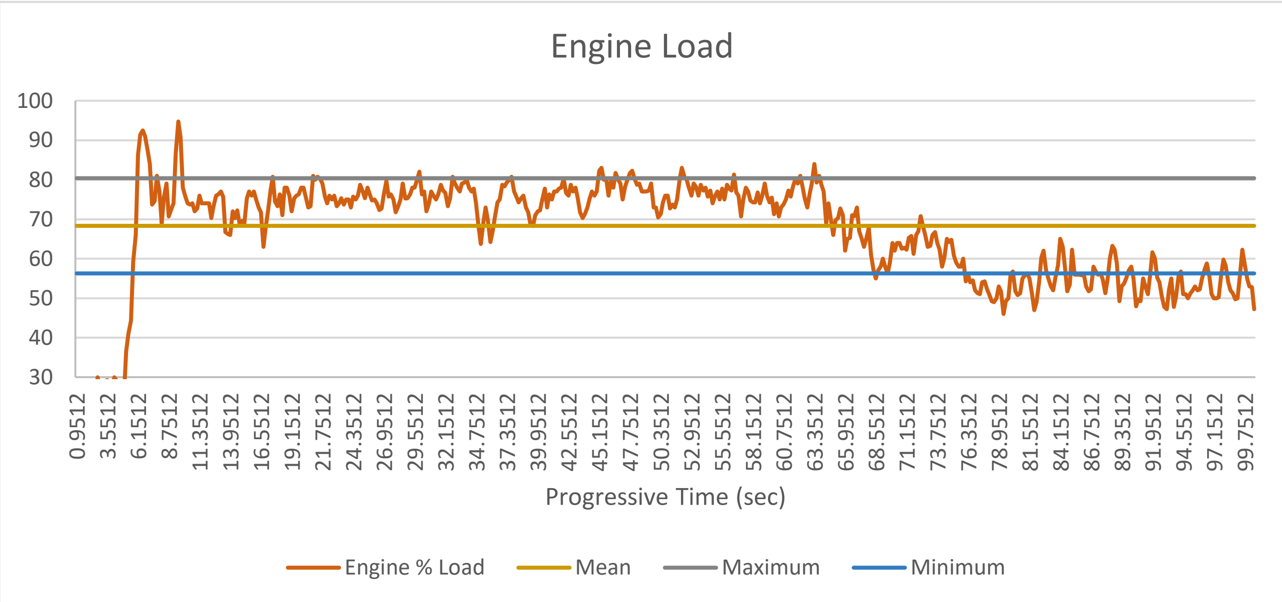

Rear Hitch %
35
30
25
20
15
10
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1930
1920
1910
1900
1890
1880
1870
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

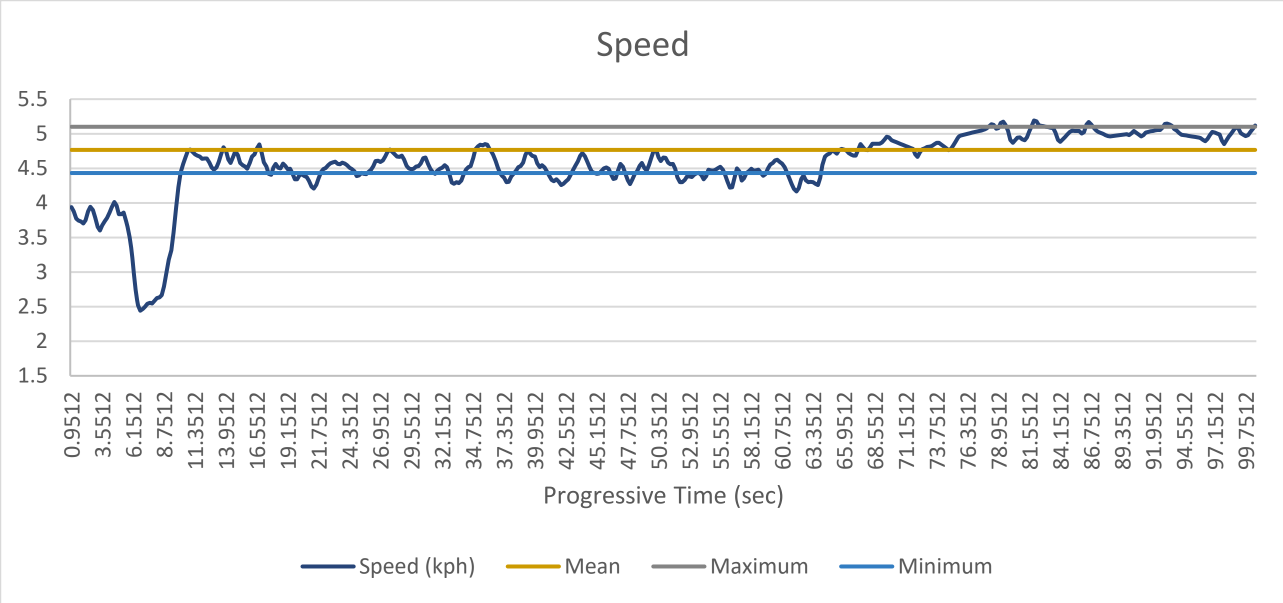
350mm – 5kph

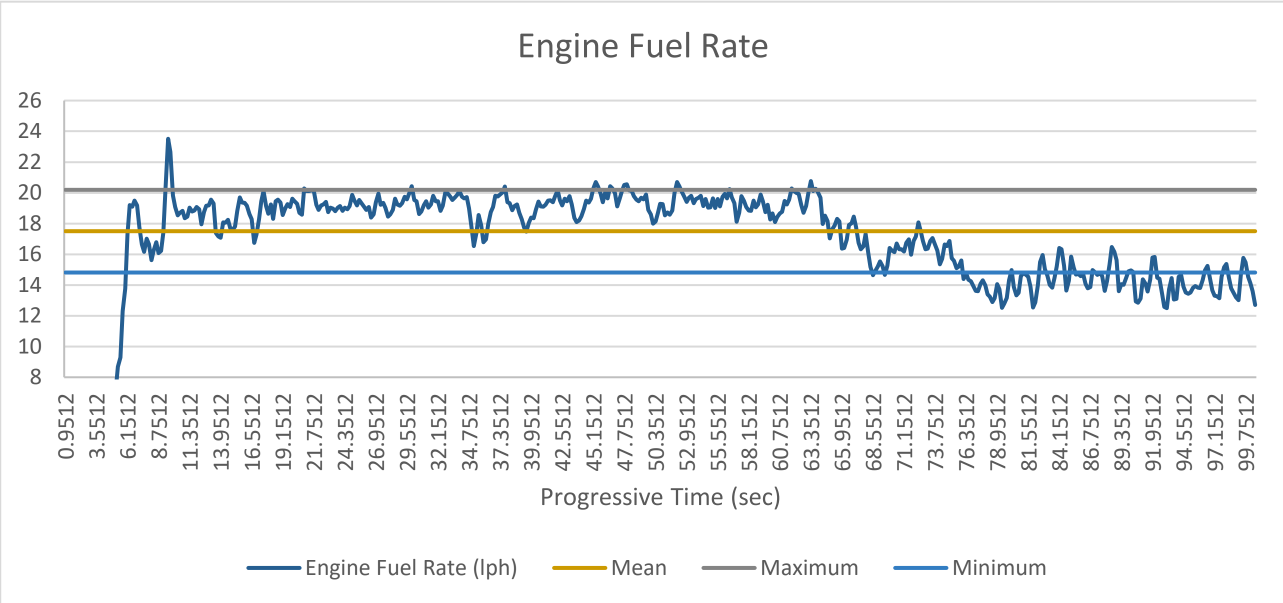


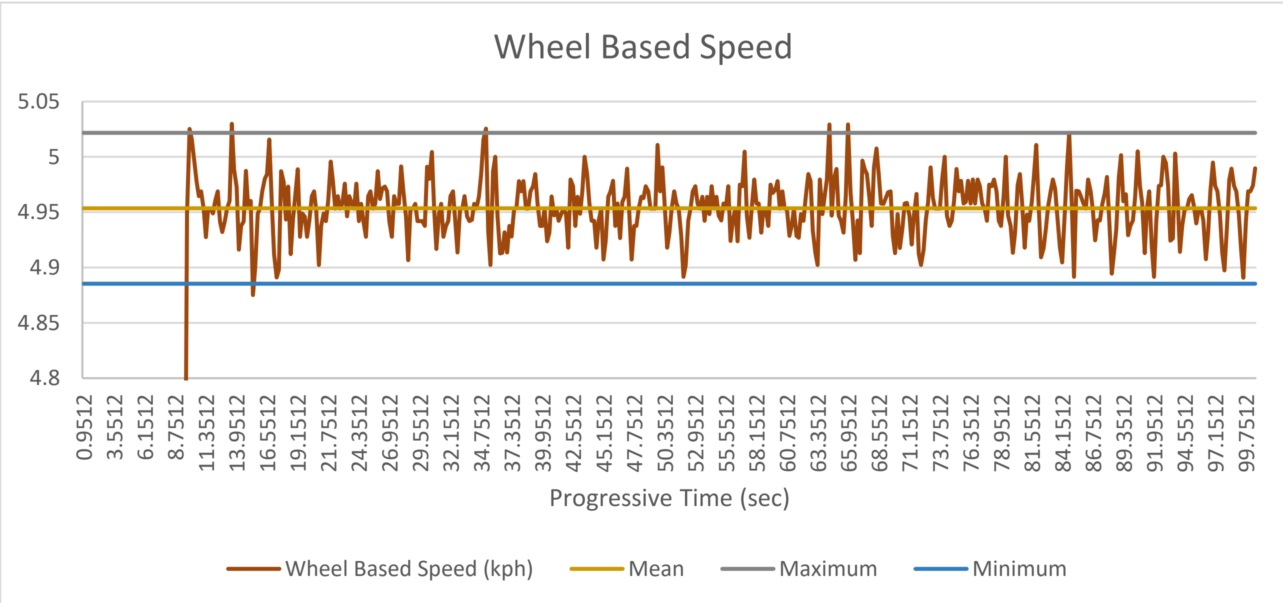
Tractor Parameters over Testing Period
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

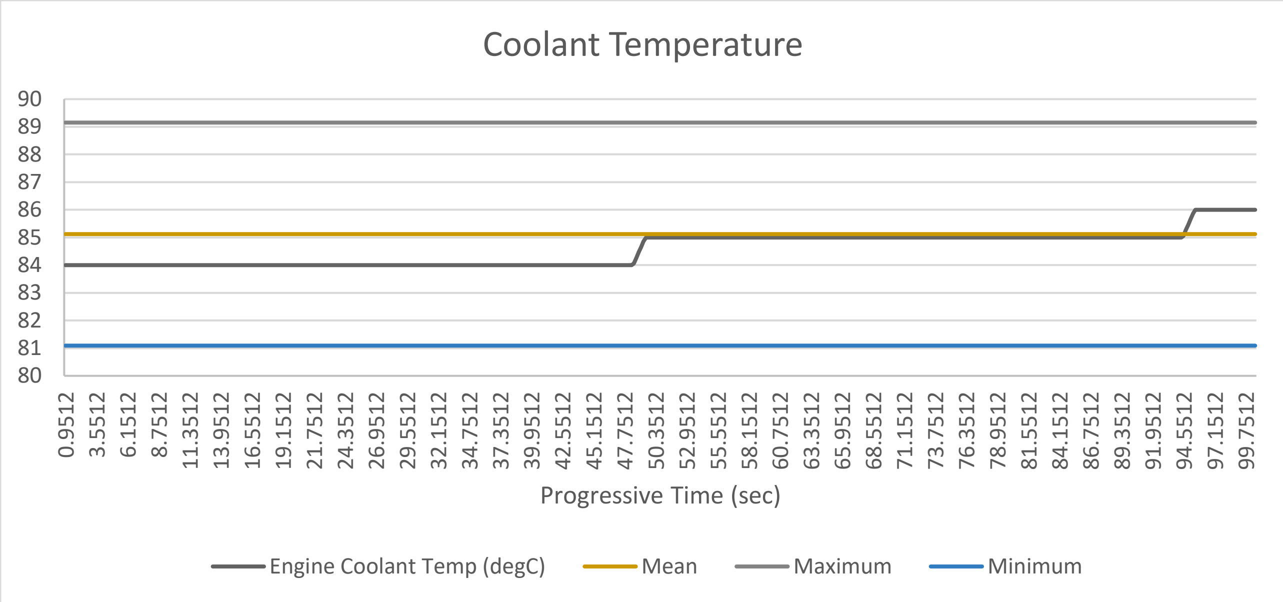


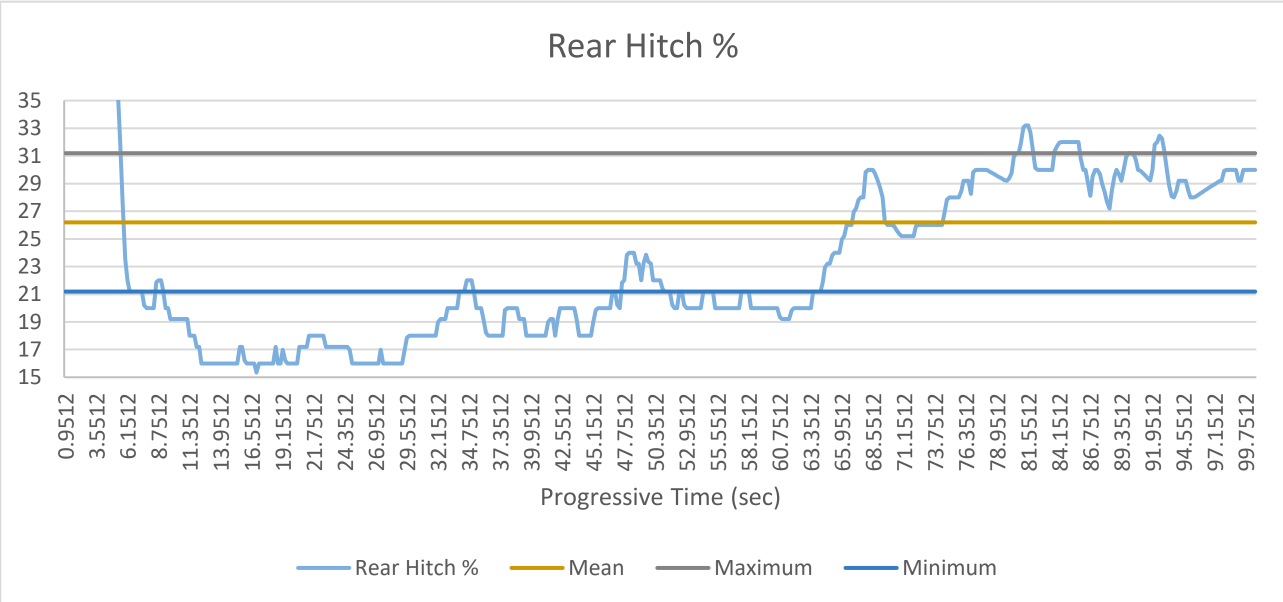
Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

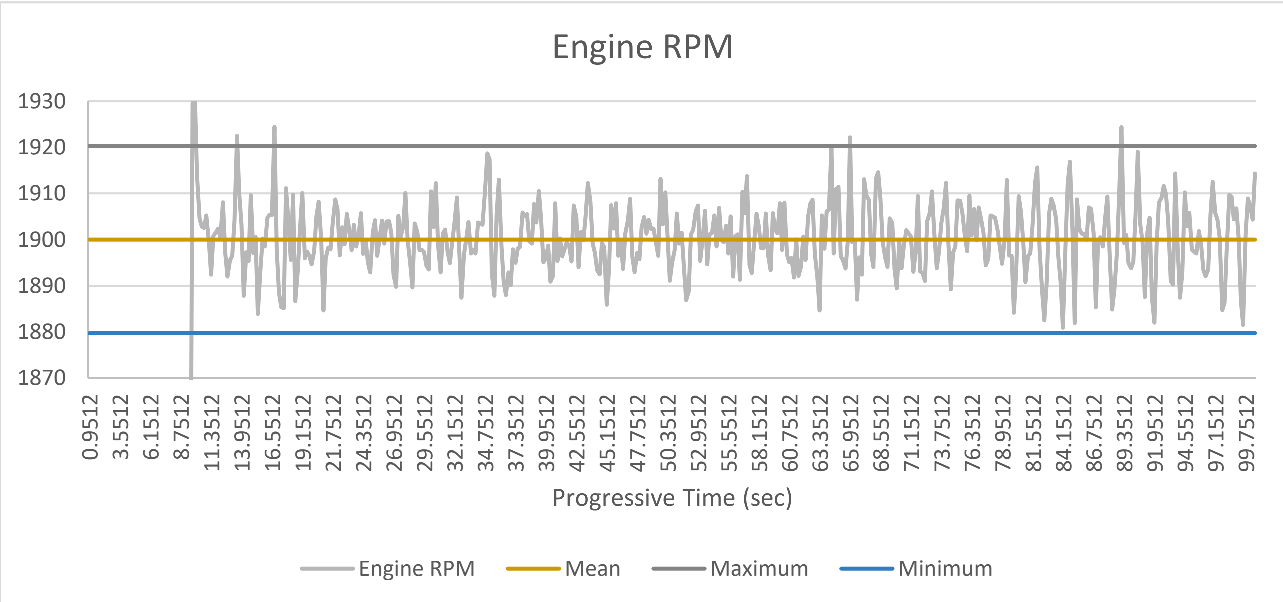

Speed
5.5
5
4.5
4
3.5
3
2.5
2
1.5
0.9512 3.5512 6.1512 8.7512 11.3512 13.9512 16.5512 19.1512 21.7512 24.3512 26.9512 29.5512 32.1512 34.7512 37.3512 39.9512 42.5512 45.1512 47.7512 50.3512 52.9512 55.5512 58.1512 60.7512 63.3512 65.9512 68.5512 71.1512 73.7512 76.3512 78.9512 81.5512 84.1512 86.7512 89.3512 91.9512 94.5512 97.1512 99.7512
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
26
24
22
20
18
16
14
12
10
8
0.9512 3.5512 6.1512 8.7512 11.3512 13.9512 16.5512 19.1512 21.7512 24.3512 26.9512 29.5512 32.1512 34.7512 37.3512 39.9512 42.5512 45.1512 47.7512 50.3512 52.9512 55.5512 58.1512 60.7512 63.3512 65.9512 68.5512 71.1512 73.7512 76.3512 78.9512 81.5512 84.1512 86.7512 89.3512 91.9512 94.5512 97.1512 99.7512
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

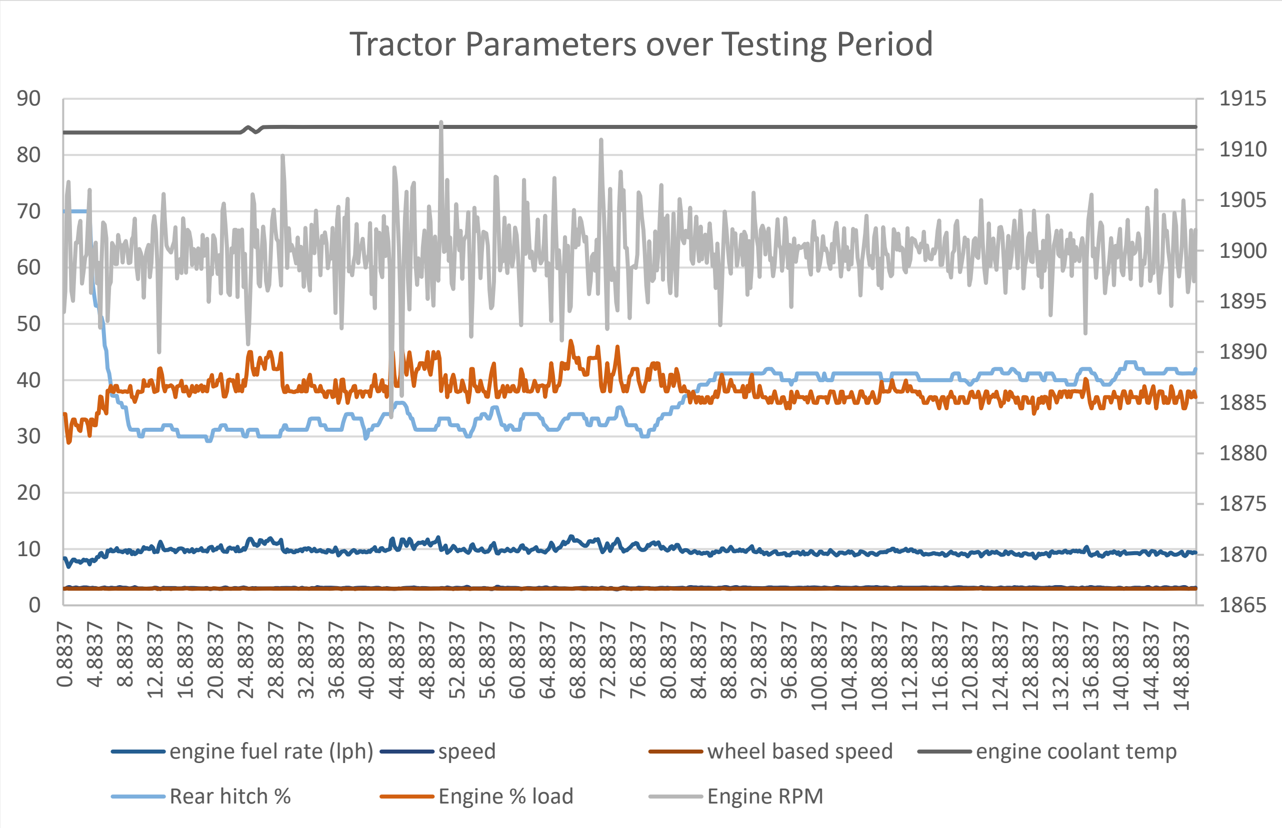

Wheel Based Speed
5.05
5
4.95
4.9
4.85
4.8
0.9512 3.5512 6.1512 8.7512 11.3512 13.9512 16.5512 19.1512 21.7512 24.3512 26.9512 29.5512 32.1512 34.7512 37.3512 39.9512 42.5512 45.1512 47.7512 50.3512 52.9512 55.5512 58.1512 60.7512 63.3512 65.9512 68.5512 71.1512 73.7512 76.3512 78.9512 81.5512 84.1512 86.7512 89.3512 91.9512 94.5512 97.1512 99.7512
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

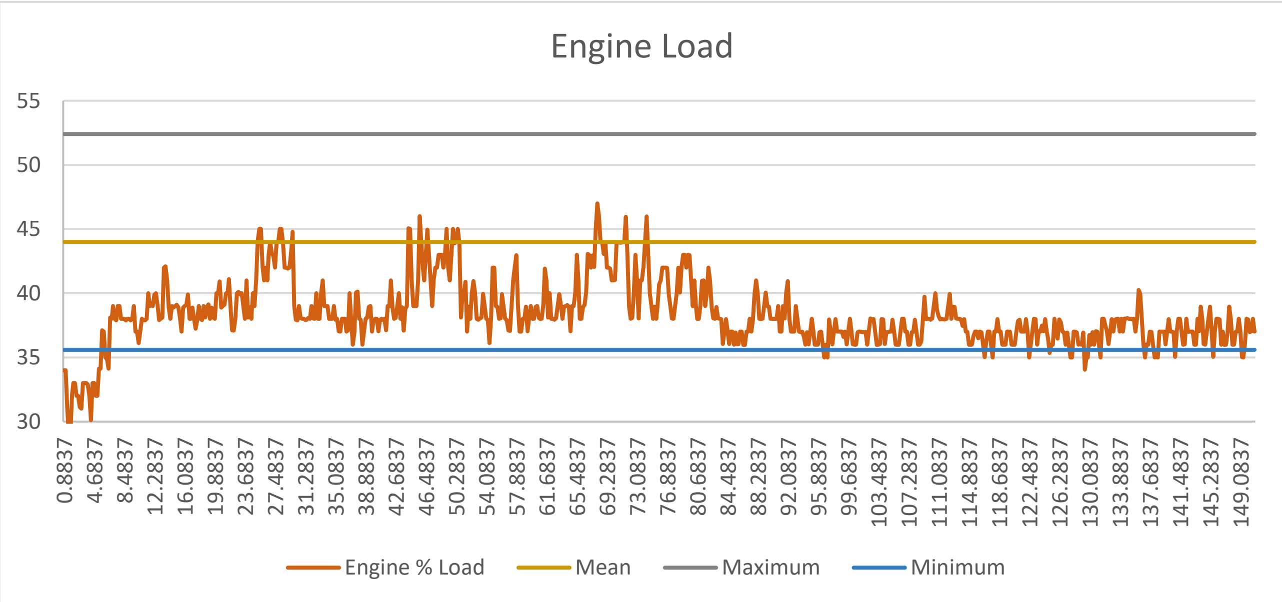

Coolant Temperature
90
89
88
87
86
85
84
83
82
81
80
0.9512
3.5512
6.1512
8.7512
11.3512
13.9512
16.5512
19.1512
21.7512
24.3512
26.9512
29.5512
32.1512
34.7512
37.3512
39.9512
42.5512
45.1512
47.7512
50.3512
52.9512
55.5512
58.1512
60.7512
63.3512
65.9512
68.5512
71.1512
73.7512
76.3512
78.9512
81.5512
84.1512
86.7512
89.3512
91.9512
94.5512
97.1512
99.7512
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

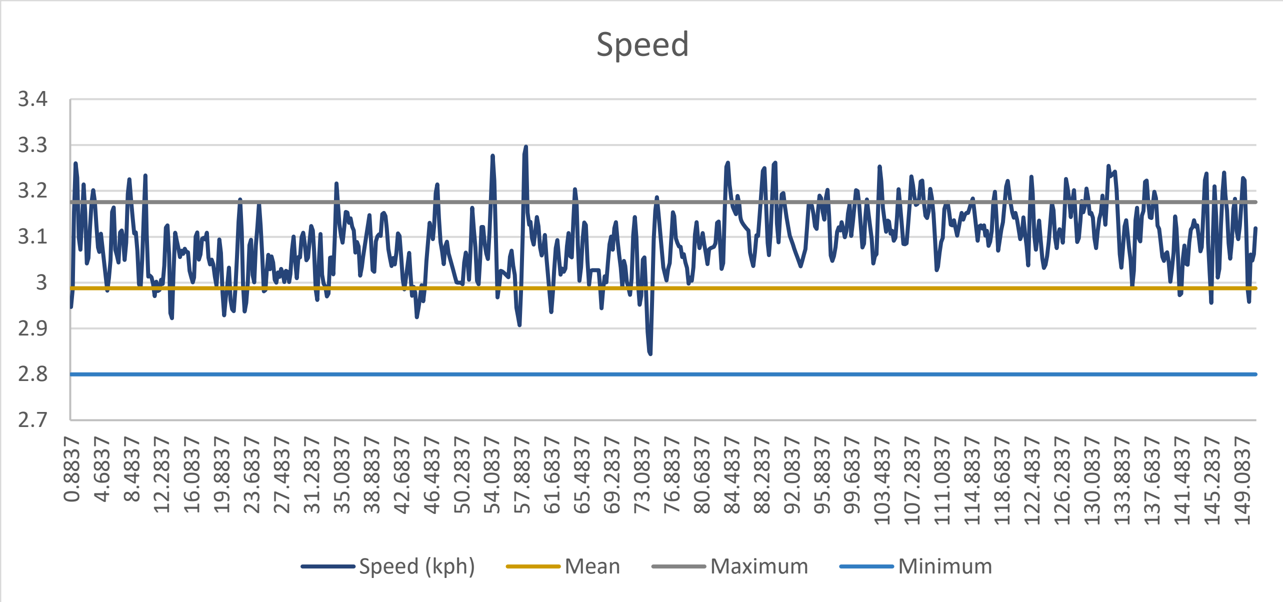

Rear Hitch %
35
33
31
29
27
25
23
21
19
17
15
0.9512
3.5512
6.1512
8.7512
11.3512
13.9512
16.5512
19.1512
21.7512
24.3512
26.9512
29.5512
32.1512
34.7512
37.3512
39.9512
42.5512
45.1512
47.7512
50.3512
52.9512
55.5512
58.1512
60.7512
63.3512
65.9512
68.5512
71.1512
73.7512
76.3512
78.9512
81.5512
84.1512
86.7512
89.3512
91.9512
94.5512
97.1512
99.7512
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

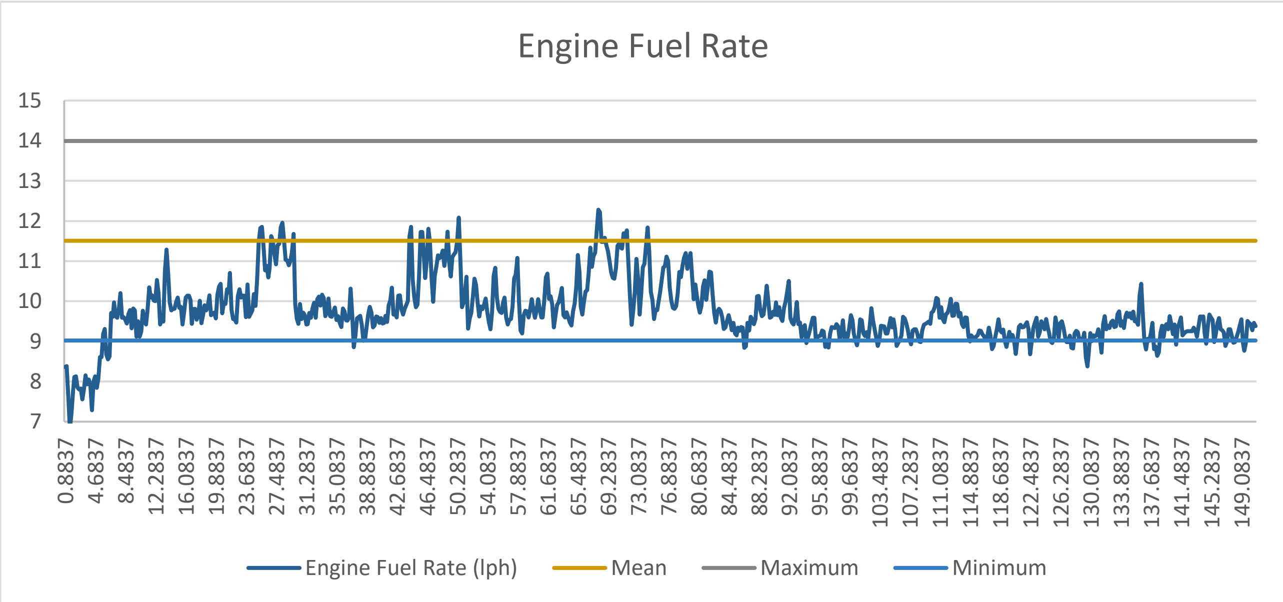

Engine RPM
1930
1920
1910
1900
1890
1880
1870
0.9512
3.5512
6.1512
8.7512
11.3512
13.9512
16.5512
19.1512
21.7512
24.3512
26.9512
29.5512
32.1512
34.7512
37.3512
39.9512
42.5512
45.1512
47.7512
50.3512
52.9512
55.5512
58.1512
60.7512
63.3512
65.9512
68.5512
71.1512
73.7512
76.3512
78.9512
81.5512
84.1512
86.7512
89.3512
91.9512
94.5512
97.1512
99.7512
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

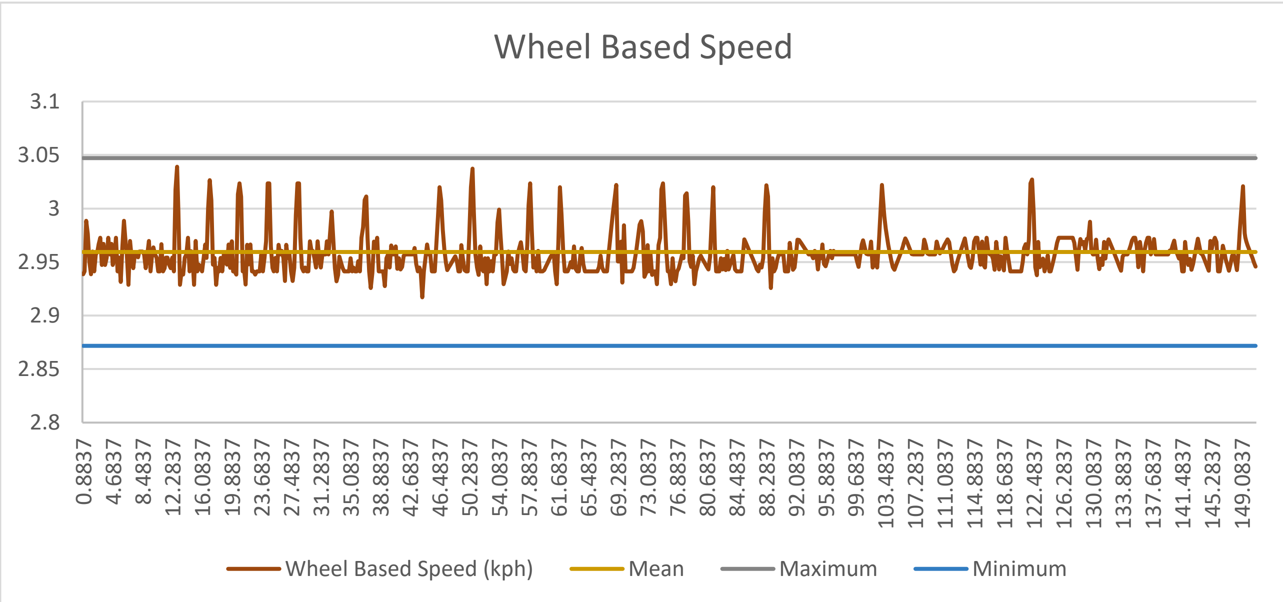
300mm – 3kph

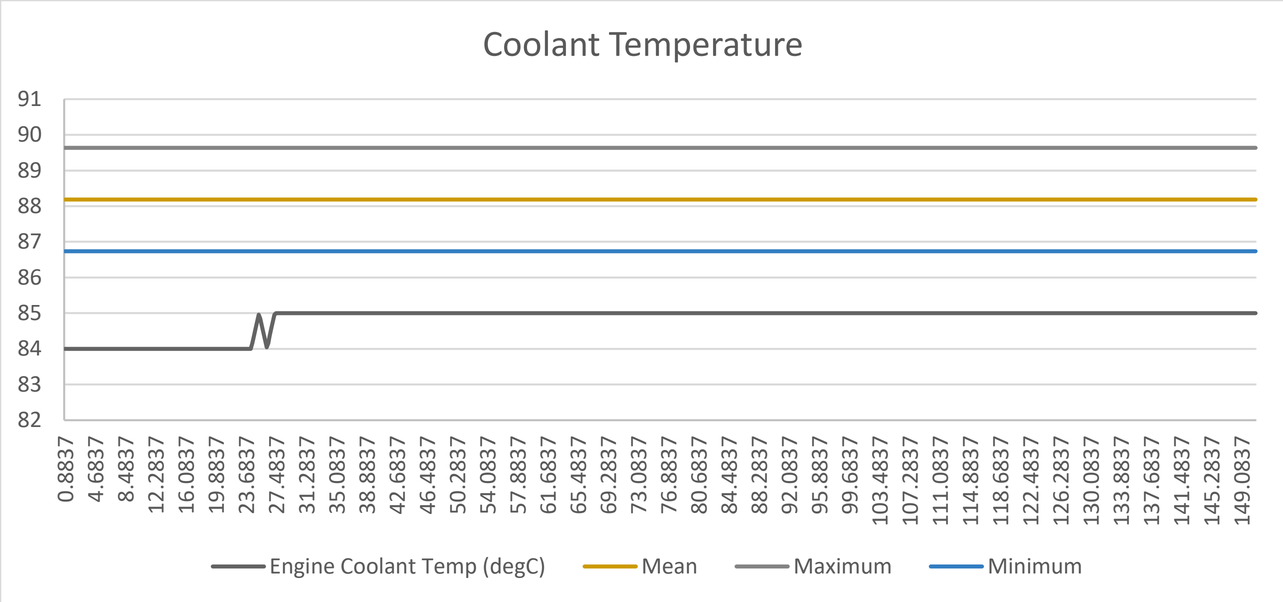

Tractor Parameters over Testing Period
0
10
20
30
40
50
60
70
80
90
1865
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
0.8837
4.8837
8.8837
12.8837
16.8837
20.8837
24.8837
28.8837
32.8837
36.8837
40.8837
44.8837
48.8837
52.8837
56.8837
60.8837
64.8837
68.8837
72.8837
76.8837
80.8837
84.8837
88.8837
92.8837
96.8837
100.8837
104.8837
108.8837
112.8837
116.8837
120.8837
124.8837
128.8837
132.8837
136.8837
140.8837
144.8837
148.8837
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

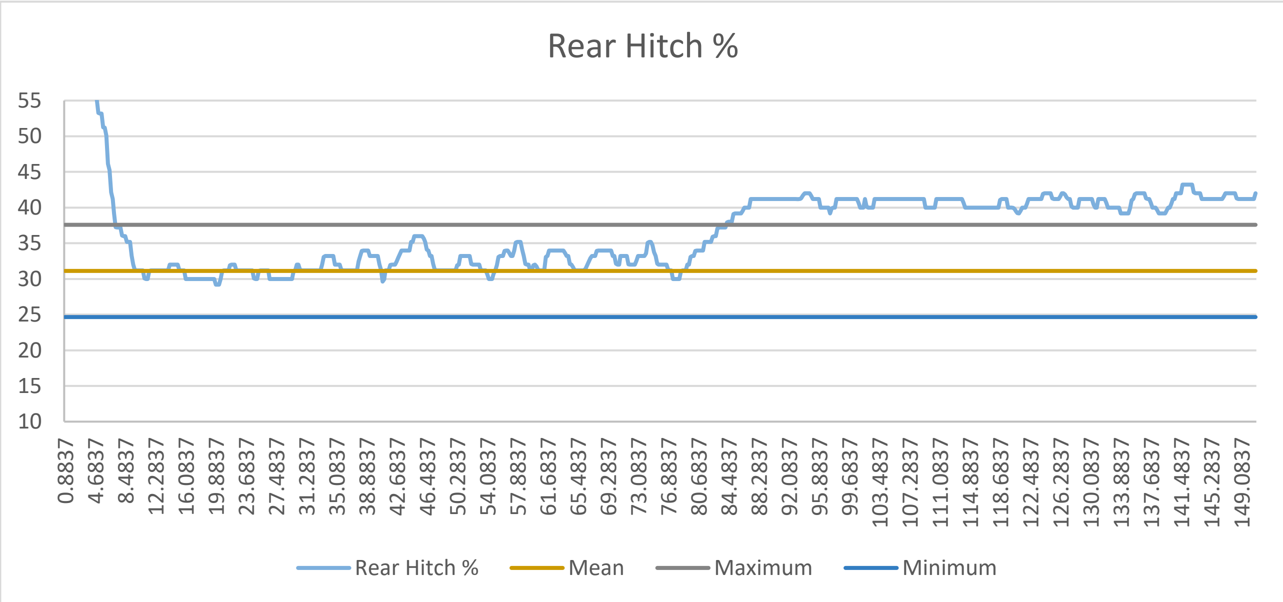

Engine Load
30
35
40
45
50
55
0.8837
4.6837
8.4837
12.2837
16.0837
19.8837
23.6837
27.4837
31.2837
35.0837
38.8837
42.6837
46.4837
50.2837
54.0837
57.8837
61.6837
65.4837
69.2837
73.0837
76.8837
80.6837
84.4837
88.2837
92.0837
95.8837
99.6837
103.4837
107.2837
111.0837
114.8837
118.6837
122.4837
126.2837
130.0837
133.8837
137.6837
141.4837
145.2837
149.0837
Engine % Load
Mean
Maximum
Minimum

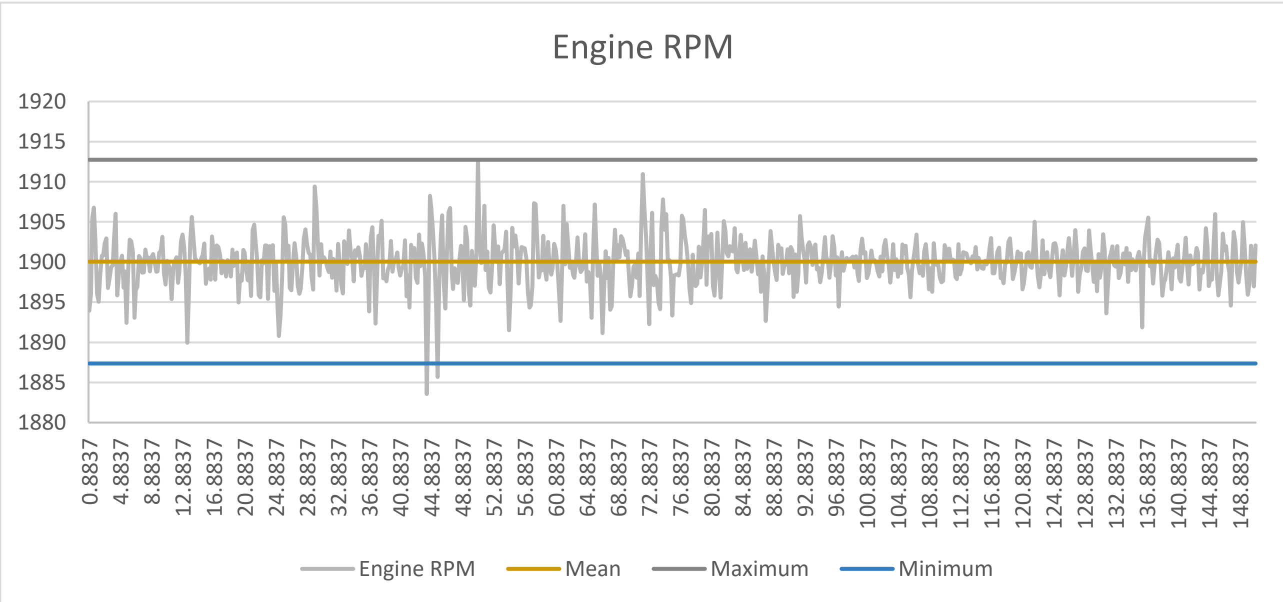

Speed
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
0.8837
4.6837
8.4837
12.2837
16.0837
19.8837
23.6837
27.4837
31.2837
35.0837
38.8837
42.6837
46.4837
50.2837
54.0837
57.8837
61.6837
65.4837
69.2837
73.0837
76.8837
80.6837
84.4837
88.2837
92.0837
95.8837
99.6837
103.4837
107.2837
111.0837
114.8837
118.6837
122.4837
126.2837
130.0837
133.8837
137.6837
141.4837
145.2837
149.0837
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
15
14
13
12
11
10
9
8
7
0.8837
4.6837
8.4837
12.2837
16.0837
19.8837
23.6837
27.4837
31.2837
35.0837
38.8837
42.6837
46.4837
50.2837
54.0837
57.8837
61.6837
65.4837
69.2837
73.0837
76.8837
80.6837
84.4837
88.2837
92.0837
95.8837
99.6837
103.4837
107.2837
111.0837
114.8837
118.6837
122.4837
126.2837
130.0837
133.8837
137.6837
141.4837
145.2837
149.0837
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

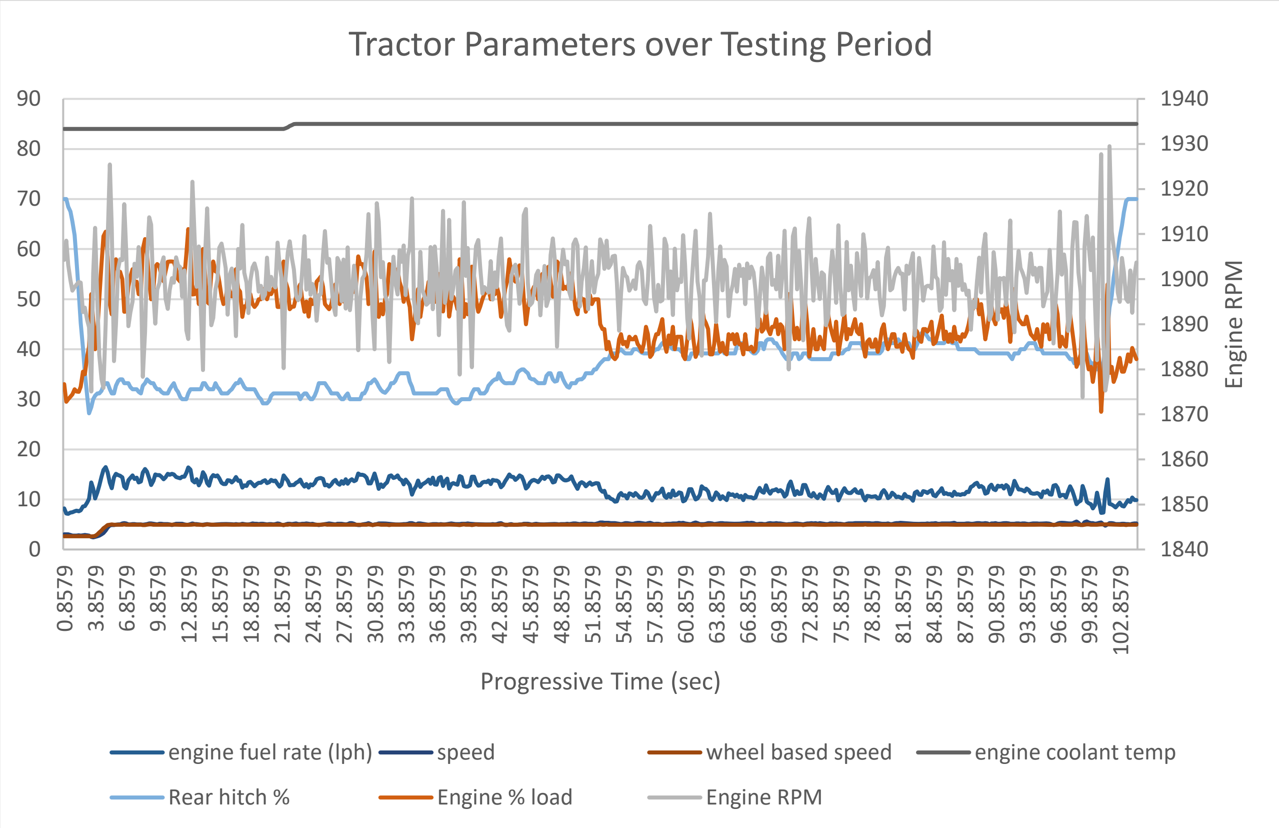

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
0.8837
4.6837
8.4837
12.2837
16.0837
19.8837
23.6837
27.4837
31.2837
35.0837
38.8837
42.6837
46.4837
50.2837
54.0837
57.8837
61.6837
65.4837
69.2837
73.0837
76.8837
80.6837
84.4837
88.2837
92.0837
95.8837
99.6837
103.4837
107.2837
111.0837
114.8837
118.6837
122.4837
126.2837
130.0837
133.8837
137.6837
141.4837
145.2837
149.0837
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

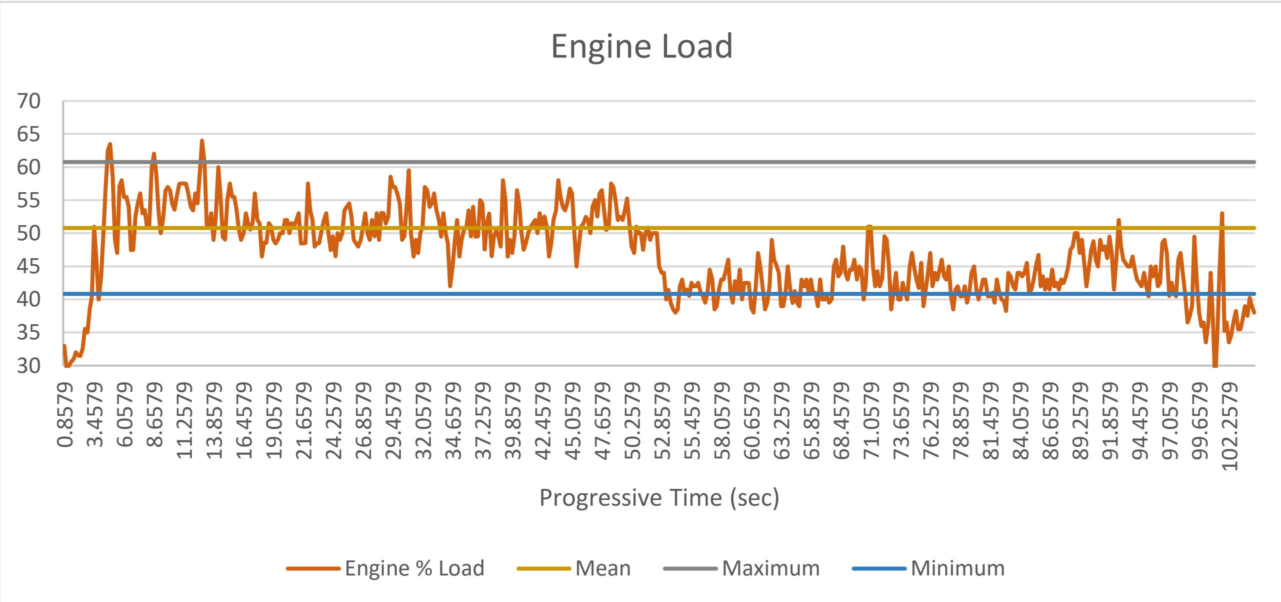

Rear Hitch %
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
Engine RPM
Mean
Maximum
Minimum

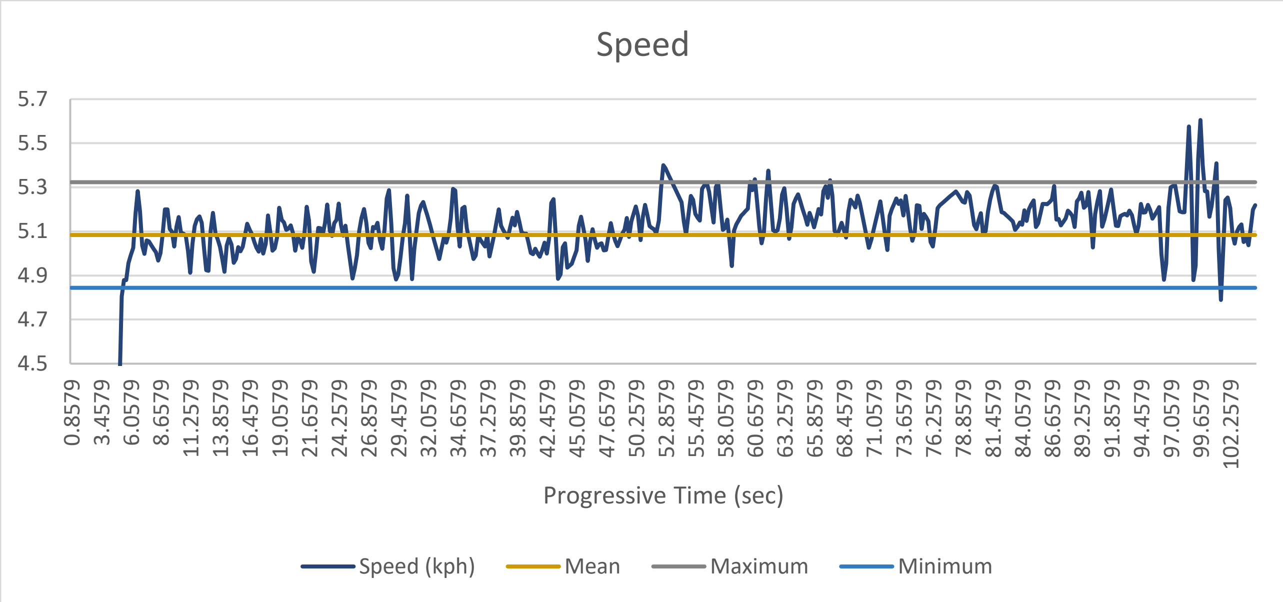
300mm – 5kph



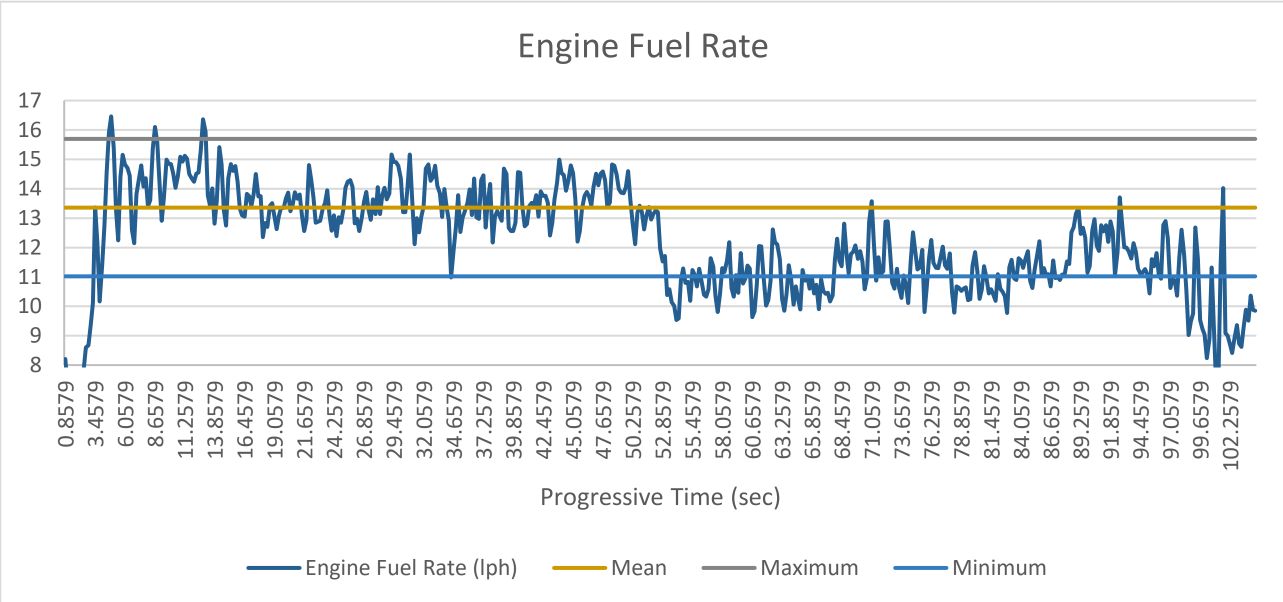
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
Engine RPM
0.8579
3.8579
6.8579
9.8579
12.8579
15.8579
18.8579
21.8579
24.8579
27.8579
30.8579
33.8579
36.8579
39.8579
42.8579
45.8579
48.8579
51.8579
54.8579
57.8579
60.8579
63.8579
66.8579
69.8579
72.8579
75.8579
78.8579
81.8579
84.8579
87.8579
90.8579
93.8579
96.8579
99.8579
102.8579
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM



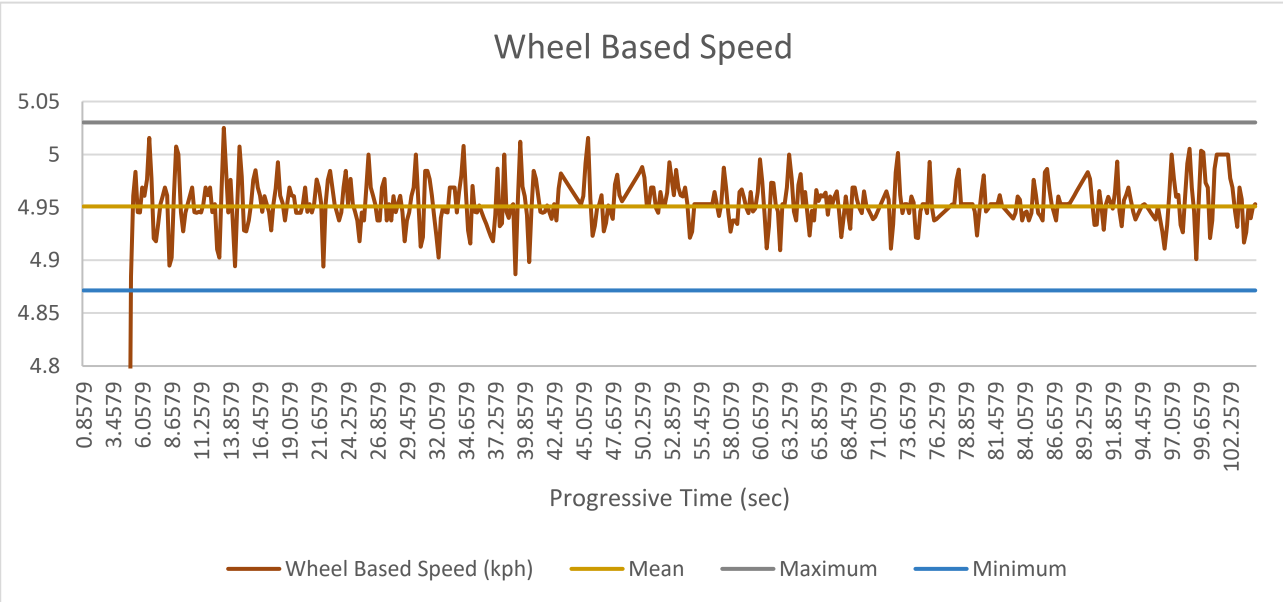
Engine Load
70
65
60
55
50
45
40
35
30
0.8579
3.4579
6.0579
8.6579
11.2579
13.8579
16.4579
19.0579
21.6579
24.2579
26.8579
29.4579
32.0579
34.6579
37.2579
39.8579
42.4579
45.0579
47.6579
50.2579
52.8579
55.4579
58.0579
60.6579
63.2579
65.8579
68.4579
71.0579
73.6579
76.2579
78.8579
81.4579
84.0579
86.6579
89.2579
91.8579
94.4579
97.0579
99.6579
102.2579
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum



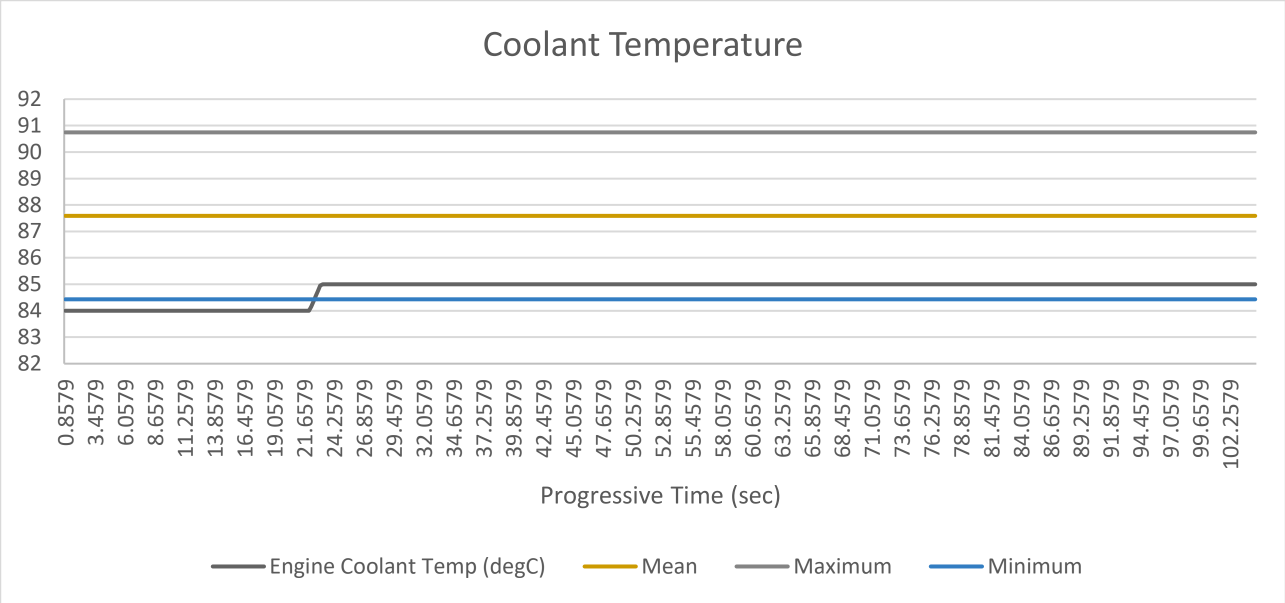
Speed
5.7
5.5
5.3
5.1
4.9
4.7
4.5
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum

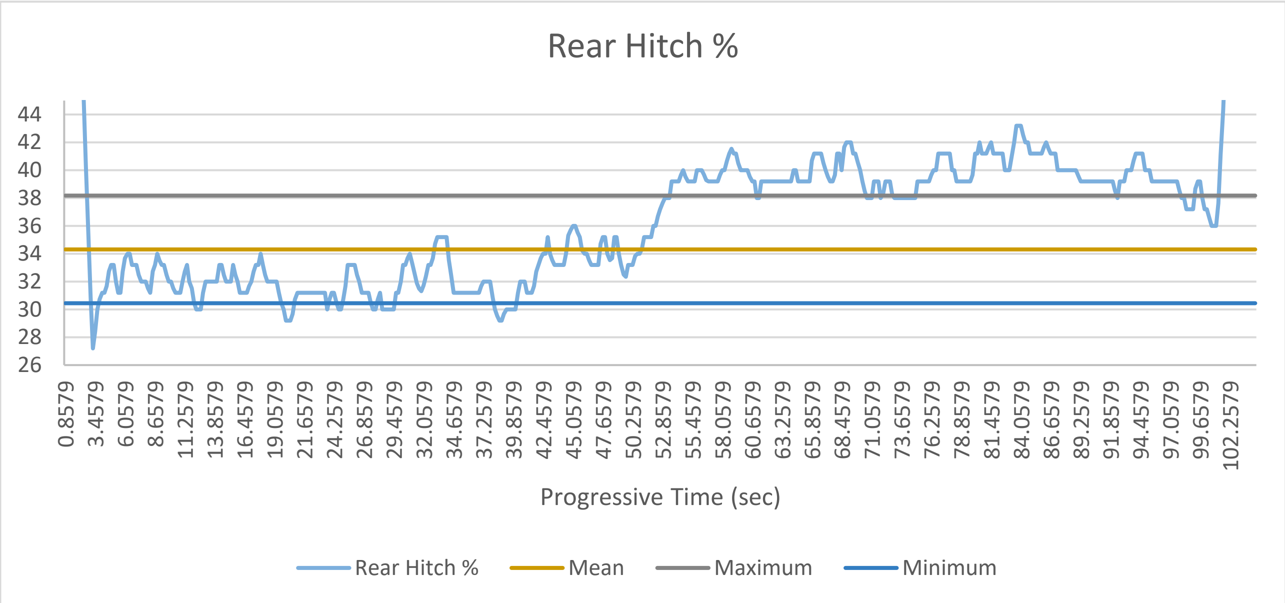


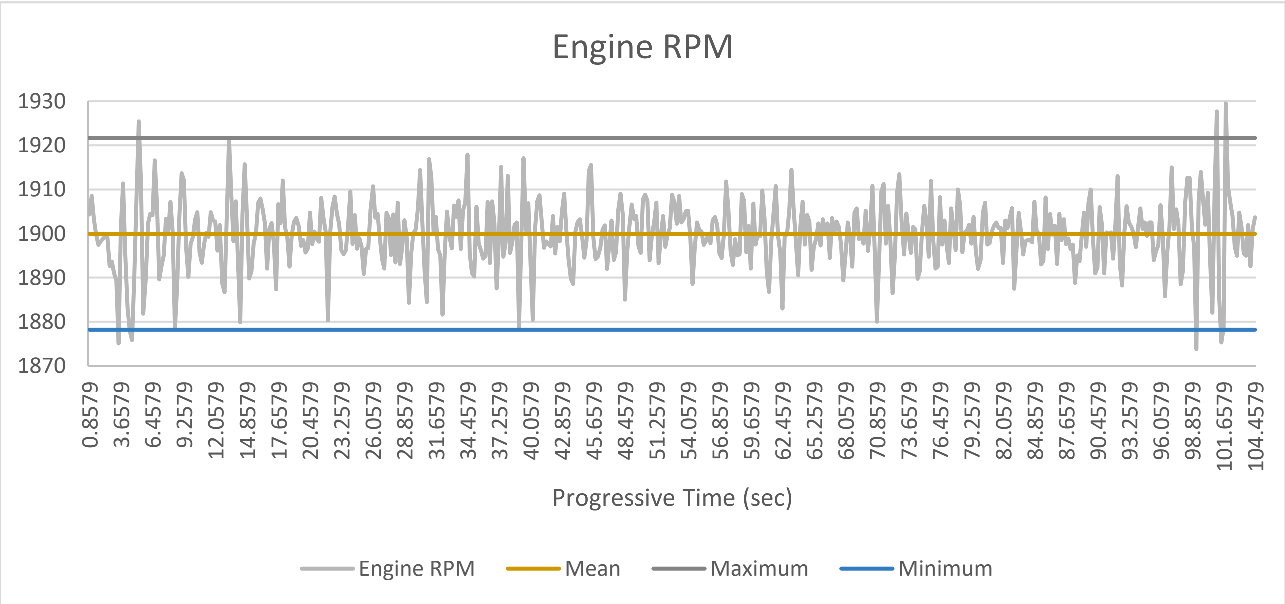
Engine Fuel Rate
17
16
15
14
13
12
11
10
9
8
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum



Wheel Based Speed
5.05
5
4.95
4.9
4.85
4.8
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

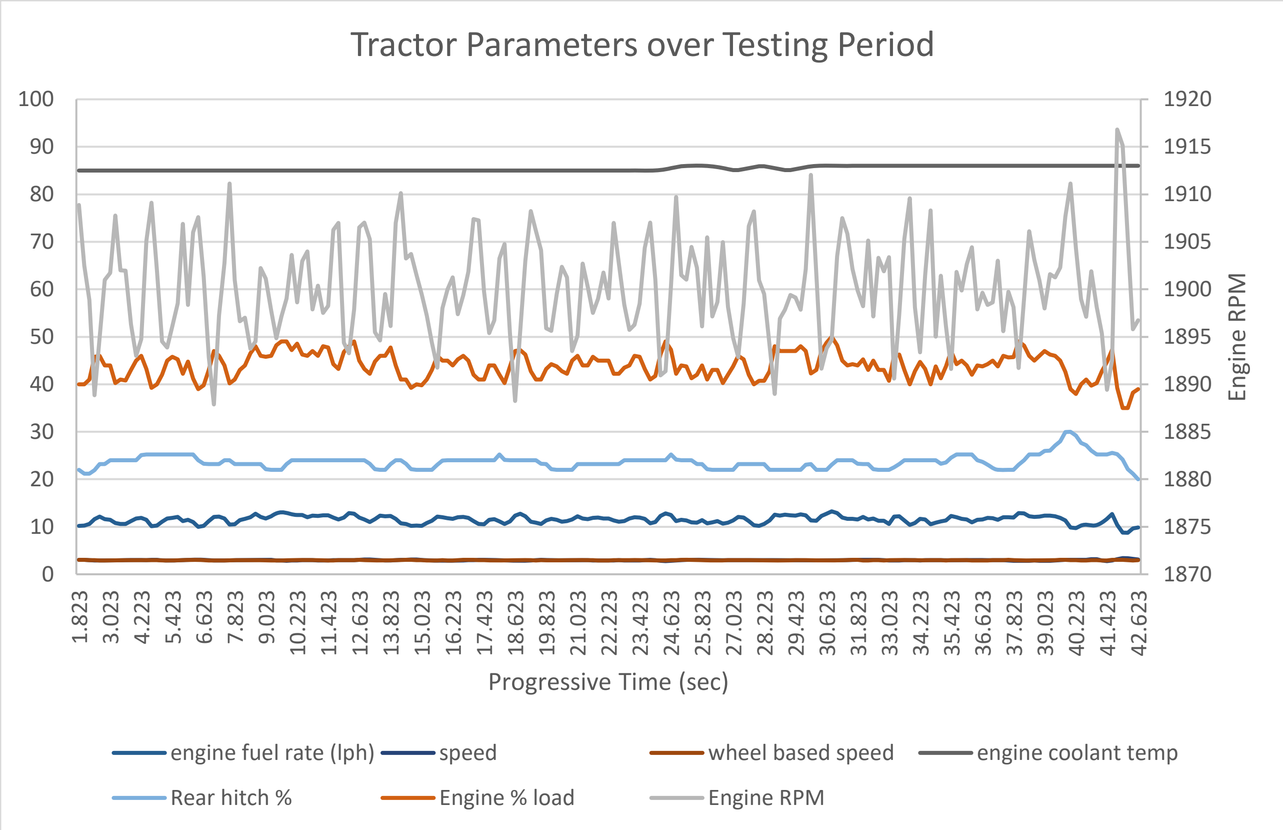

Coolant Temperature
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

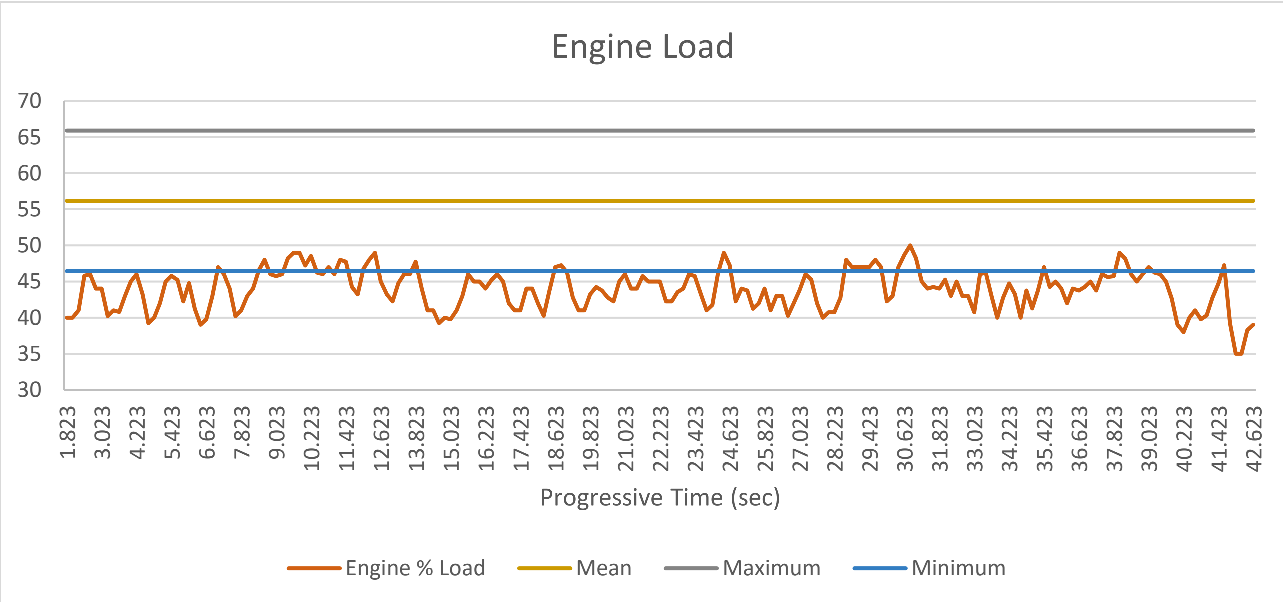

Rear Hitch %
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

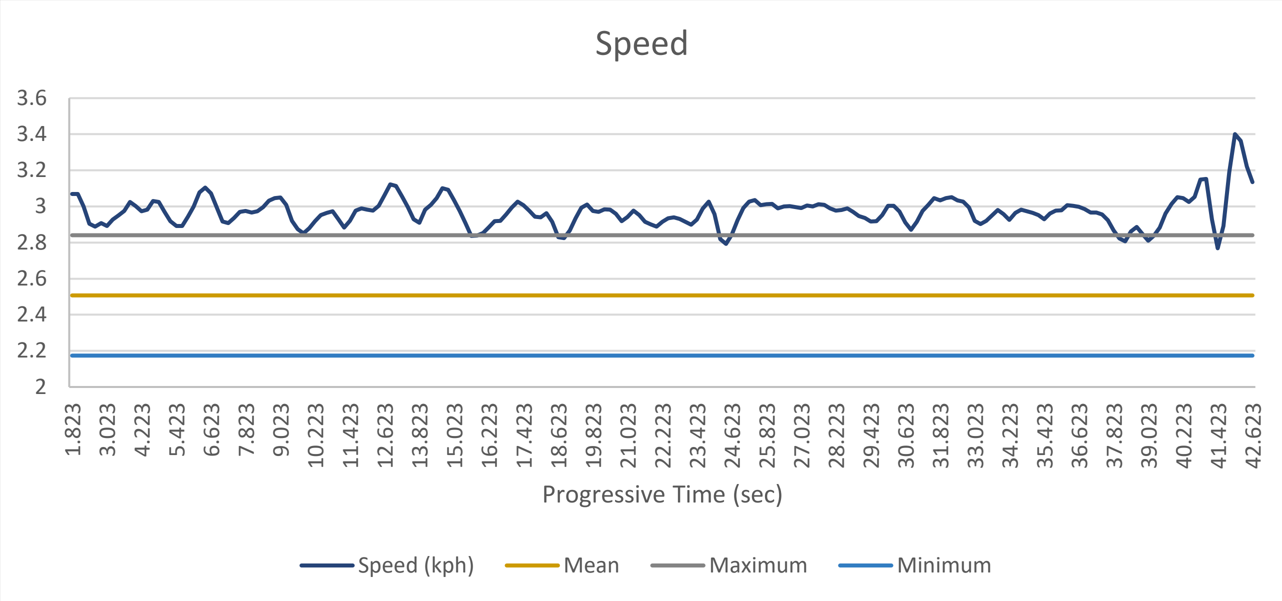

Engine RPM
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

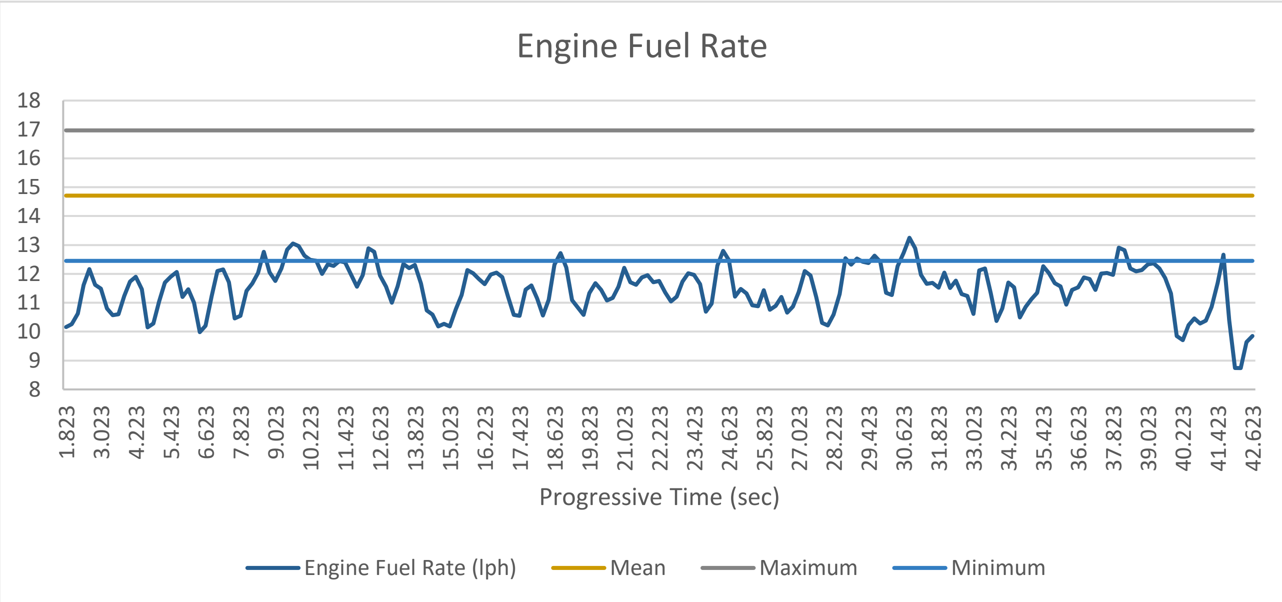
Appendix K – 3PL Deep Ripper – Failing to lift 3PL prior to headland execution data

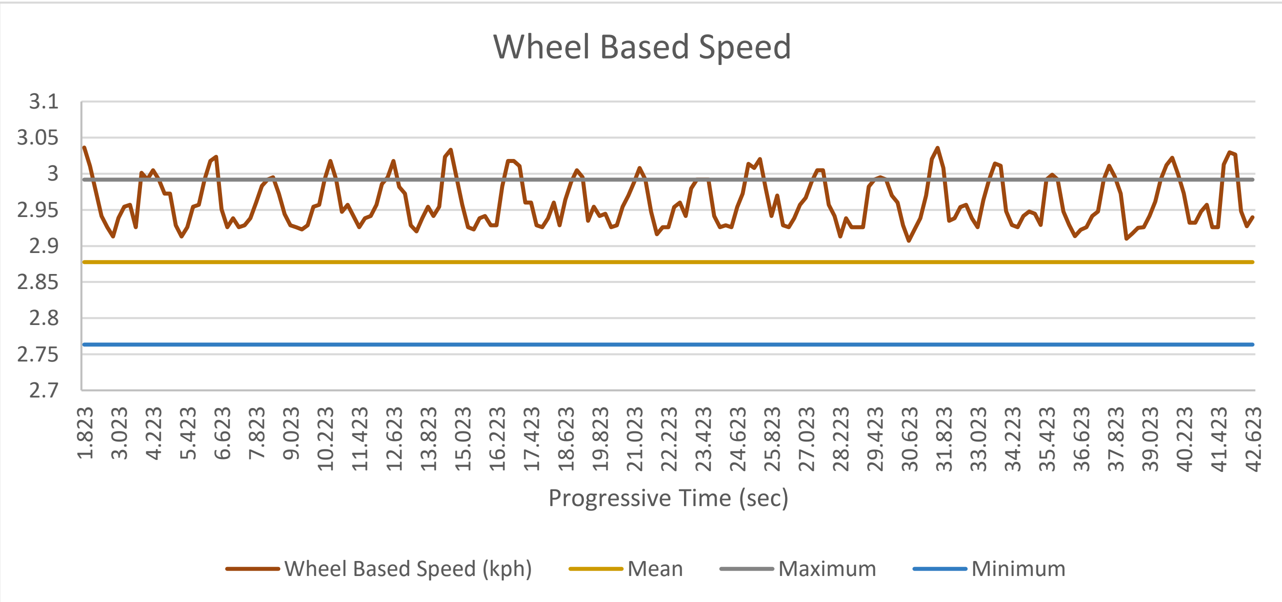
350mm – 3kph

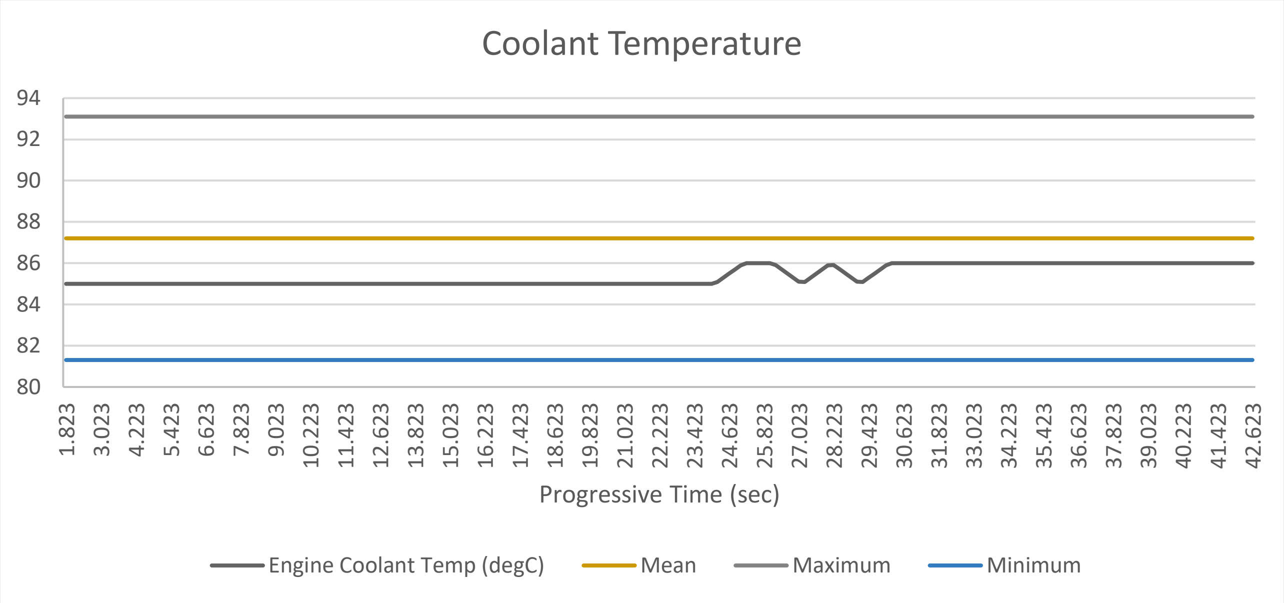


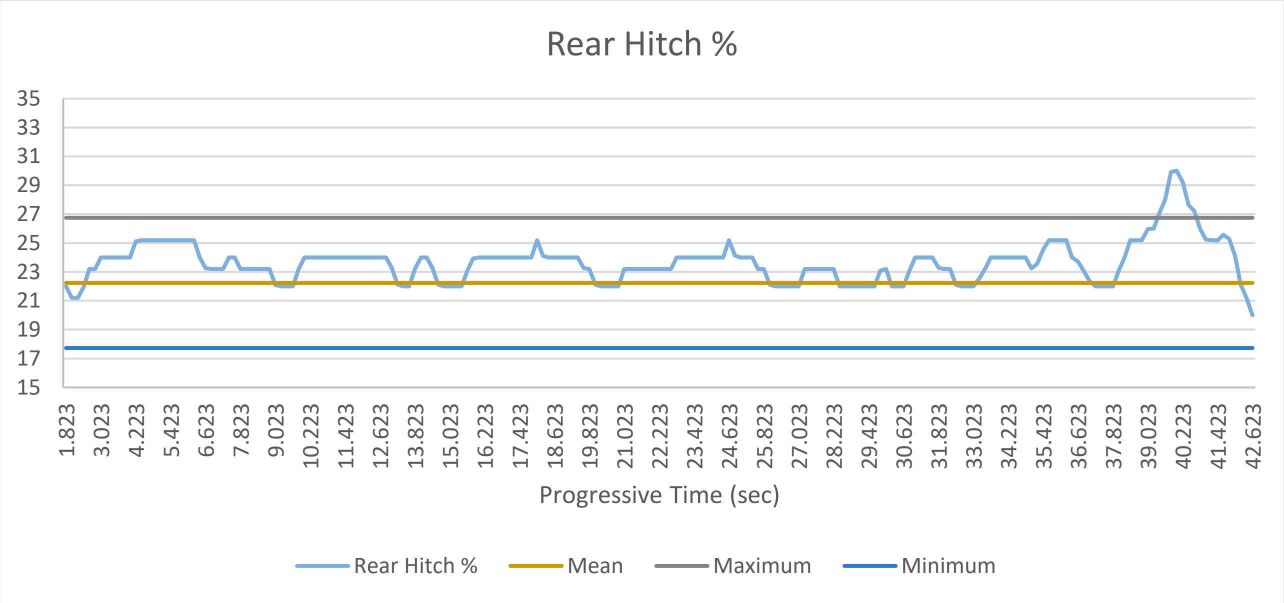


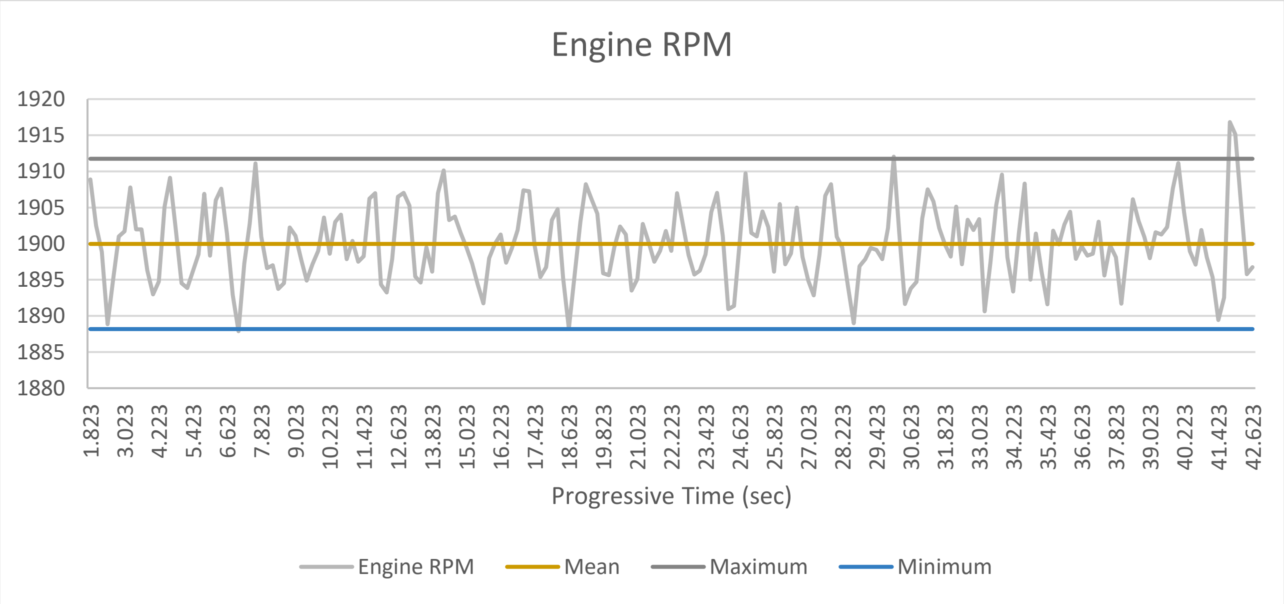

Speed
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
18
17
16
15
14
13
12
11
10
9
8
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

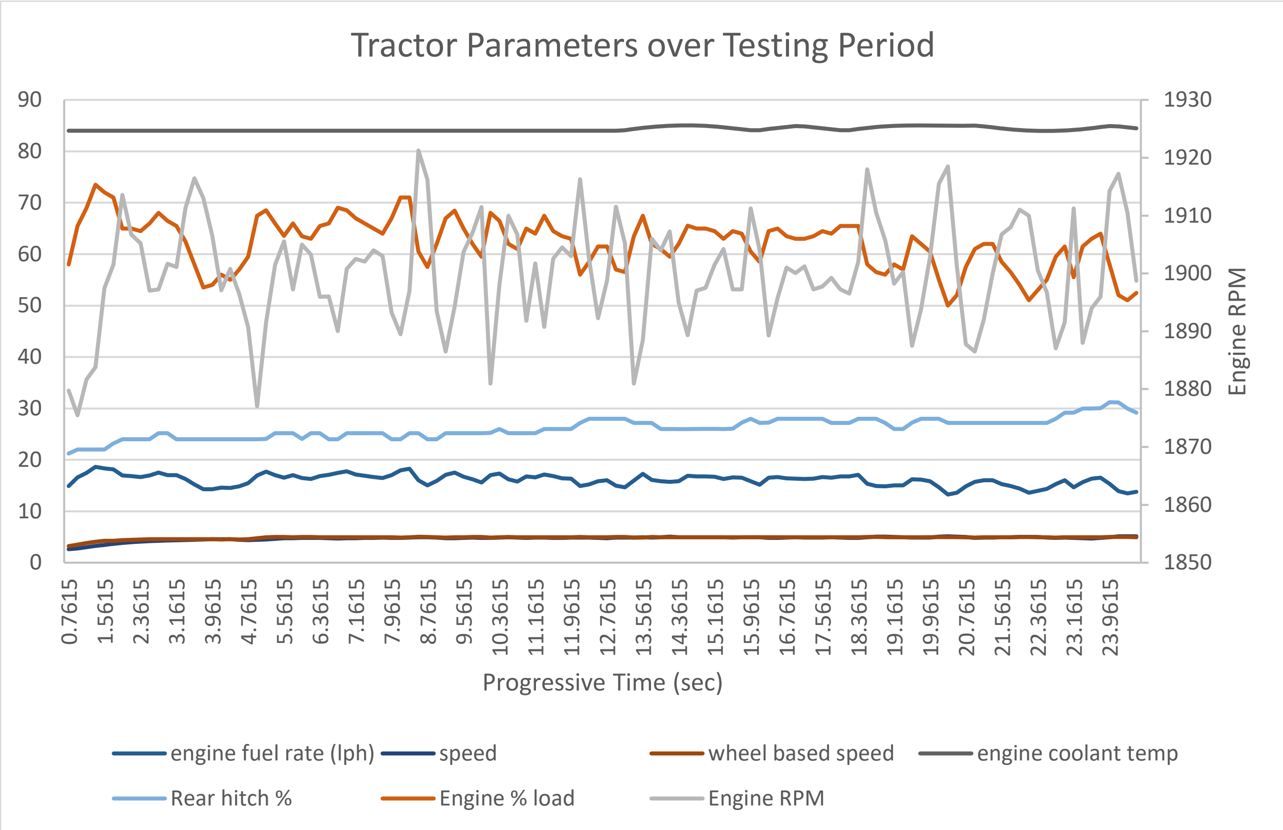

Wheel Based Speed
3.1
3.05
3
2.95
2.9
2.85
2.8
2.75
2.7
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

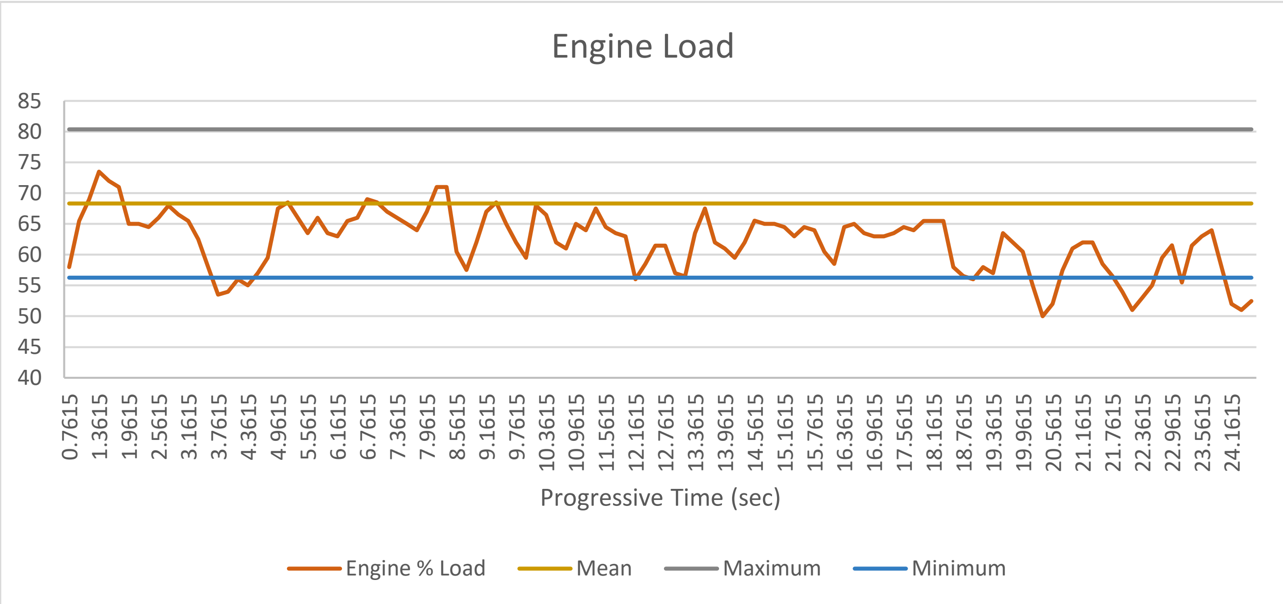

Coolant Temperature
94
92
90
88
86
84
82
80
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

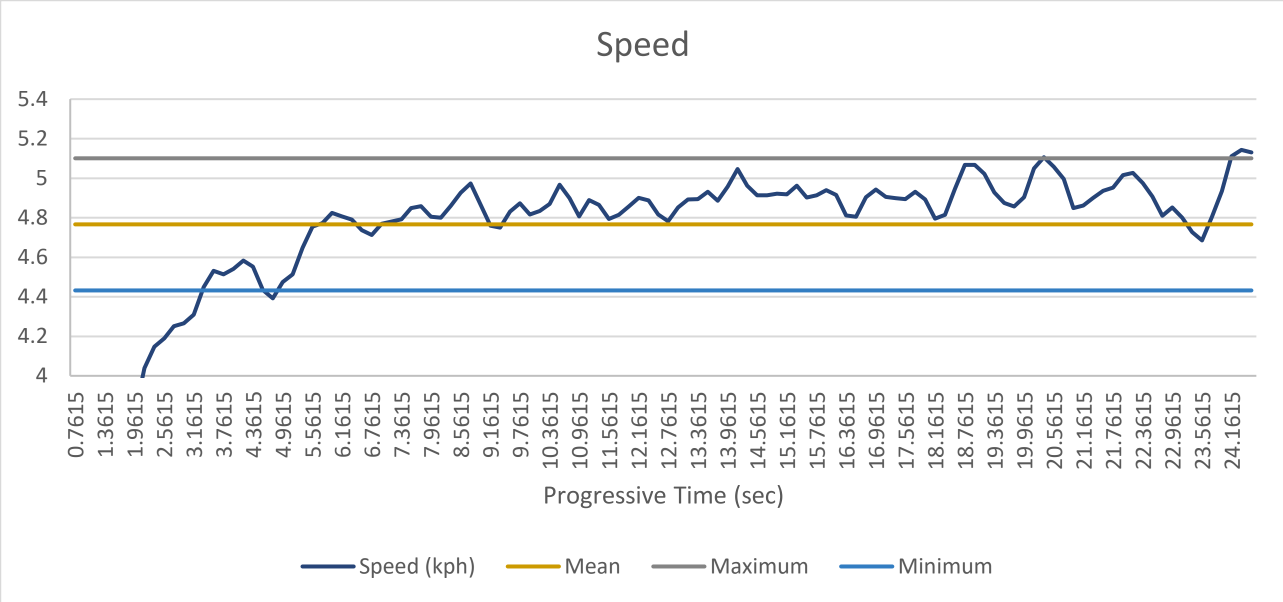

Rear Hitch %
35
33
31
29
27
25
23
21
19
17
15
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1920
1915
1910
1905
1900
1895
1890
1885
1880
1.823 3.023 4.223 5.423 6.623 7.823 9.023 10.223 11.423 12.623 13.823 15.023 16.223 17.423 18.623 19.823 21.023 22.223 23.423 24.623 25.823 27.023 28.223 29.423 30.623 31.823 33.023 34.223 35.423 36.623 37.823 39.023 40.223 41.423 42.623
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

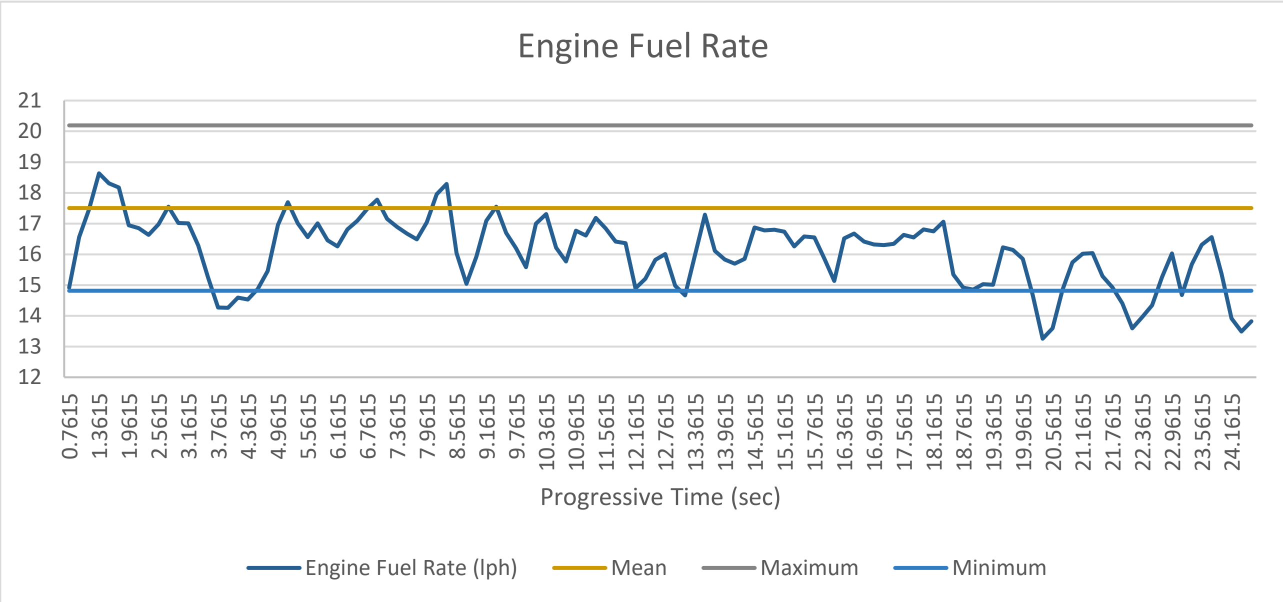
350mm – 5kph


Tractor Parameters over Testing Period
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

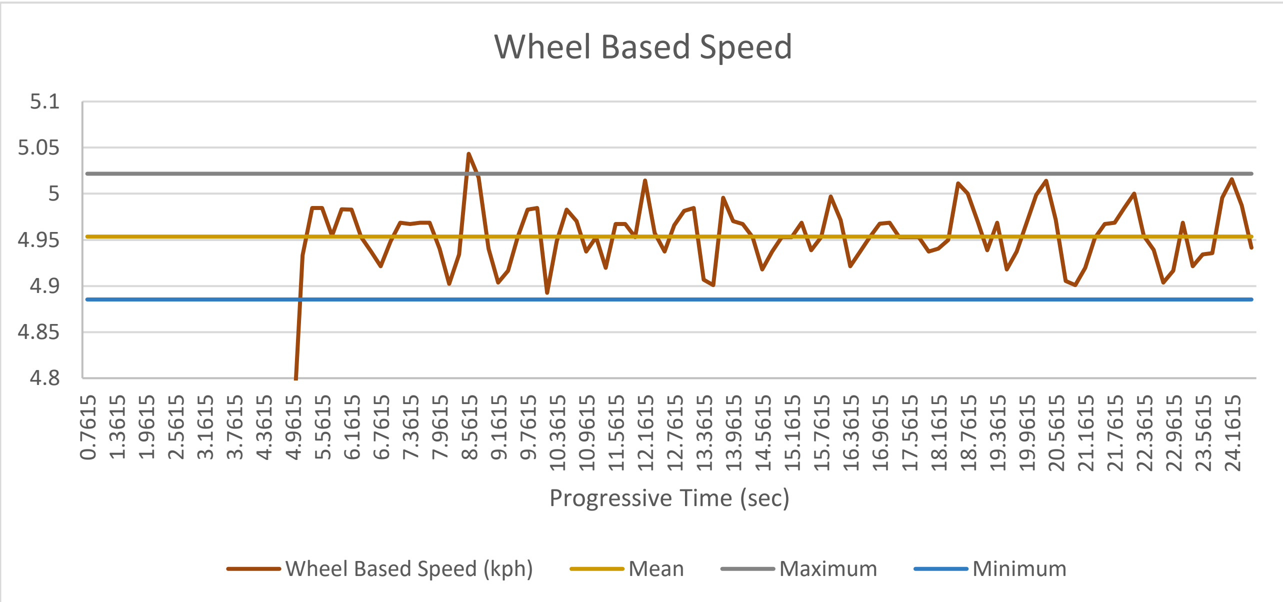

Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum



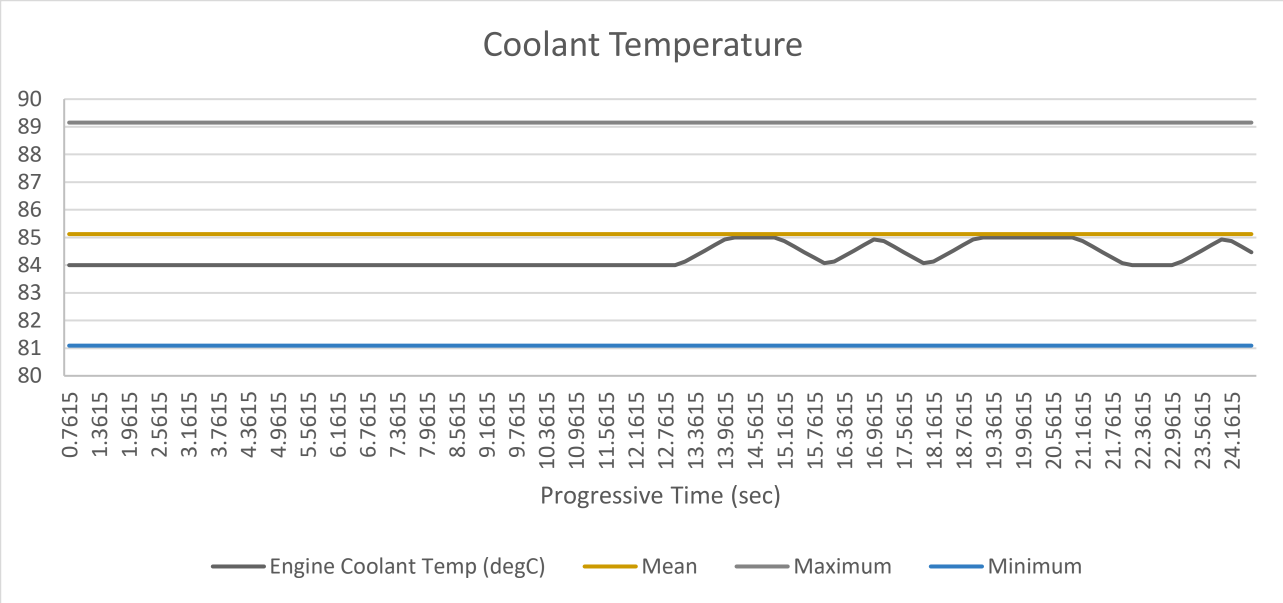
Speed
5.4
5.2
5
4.8
4.6
4.4
4.2
4
0.7615
1.3615
1.9615
2.5615
3.1615
3.7615
4.3615
4.9615
5.5615
6.1615
6.7615
7.3615
7.9615
8.5615
9.1615
9.7615
10.3615
10.9615
11.5615
12.1615
12.7615
13.3615
13.9615
14.5615
15.1615
15.7615
16.3615
16.9615
17.5615
18.1615
18.7615
19.3615
19.9615
20.5615
21.1615
21.7615
22.3615
22.9615
23.5615
24.1615
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum

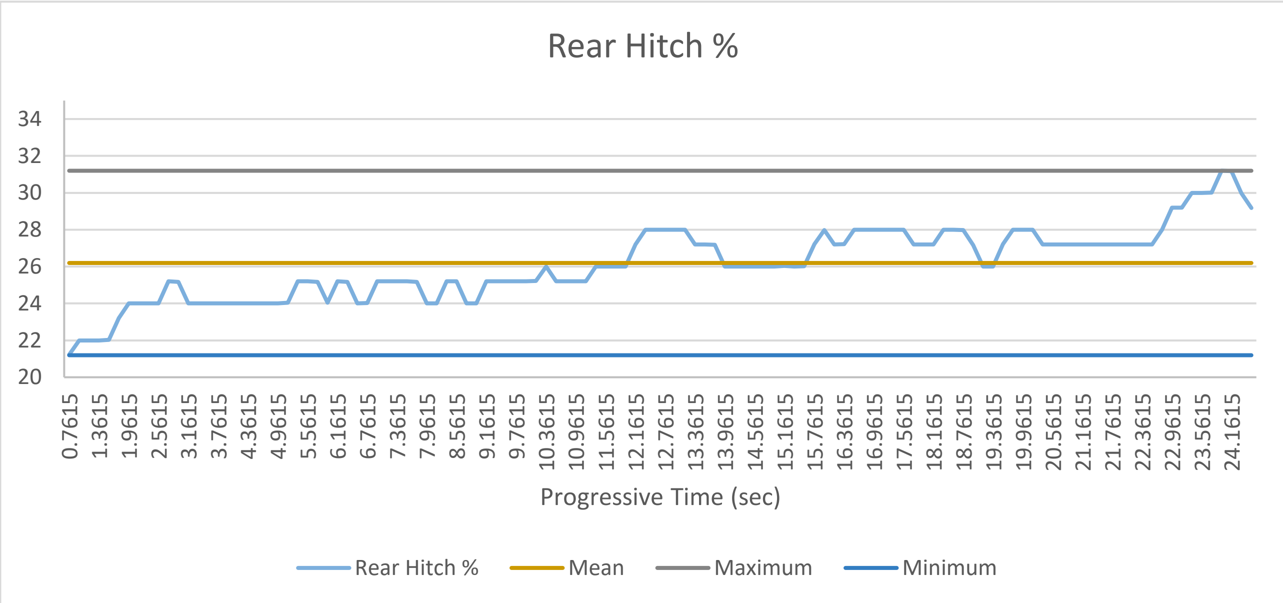


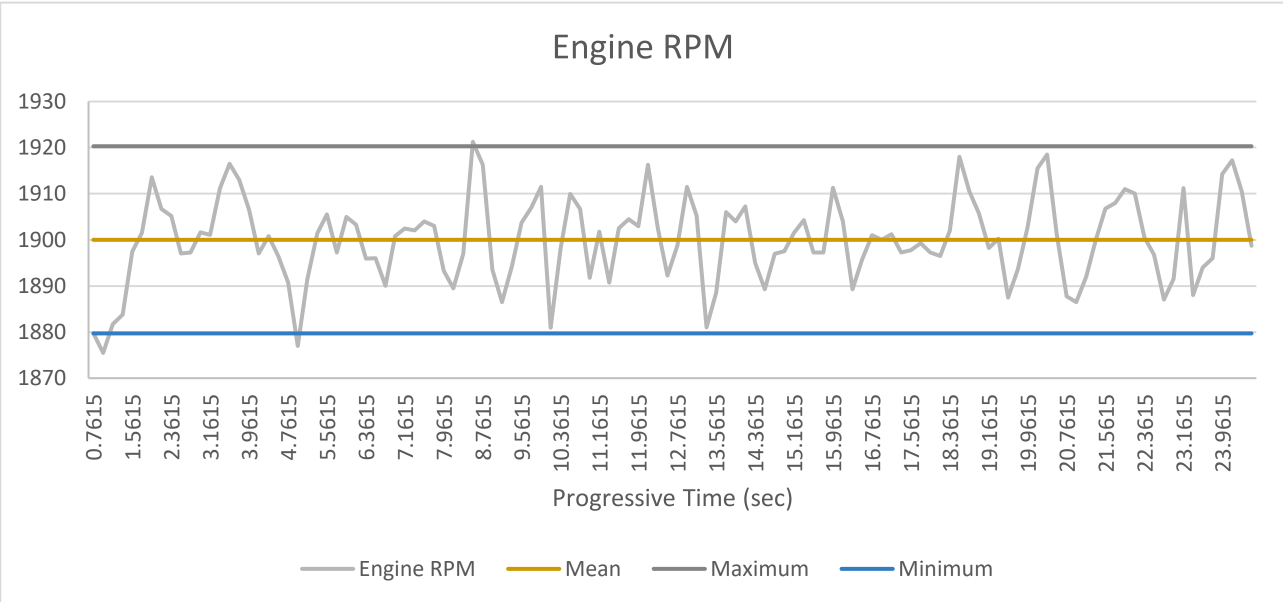
Engine Fuel Rate
21
20
19
18
17
16
15
14
13
12
0.7615
1.3615
1.9615
2.5615
3.1615
3.7615
4.3615
4.9615
5.5615
6.1615
6.7615
7.3615
7.9615
8.5615
9.1615
9.7615
10.3615
10.9615
11.5615
12.1615
12.7615
13.3615
13.9615
14.5615
15.1615
15.7615
16.3615
16.9615
17.5615
18.1615
18.7615
19.3615
19.9615
20.5615
21.1615
21.7615
22.3615
22.9615
23.5615
24.1615
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum



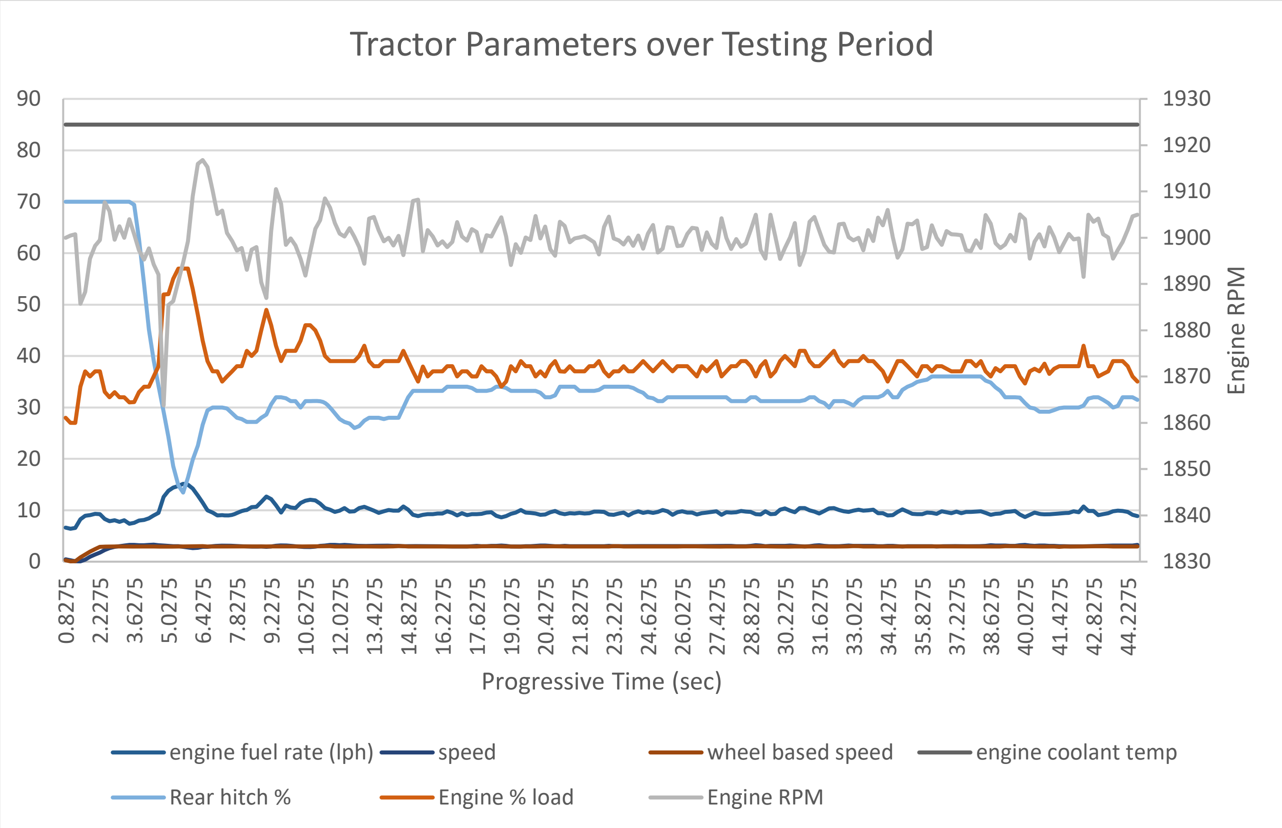
Wheel Based Speed
5.1
5.05
5
4.95
4.9
4.85
4.8
0.7615
1.3615
1.9615
2.5615
3.1615
3.7615
4.3615
4.9615
5.5615
6.1615
6.7615
7.3615
7.9615
8.5615
9.1615
9.7615
10.3615
10.9615
11.5615
12.1615
12.7615
13.3615
13.9615
14.5615
15.1615
15.7615
16.3615
16.9615
17.5615
18.1615
18.7615
19.3615
19.9615
20.5615
21.1615
21.7615
22.3615
22.9615
23.5615
24.1615
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
89
88
87
86
85
84
83
82
81
80
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

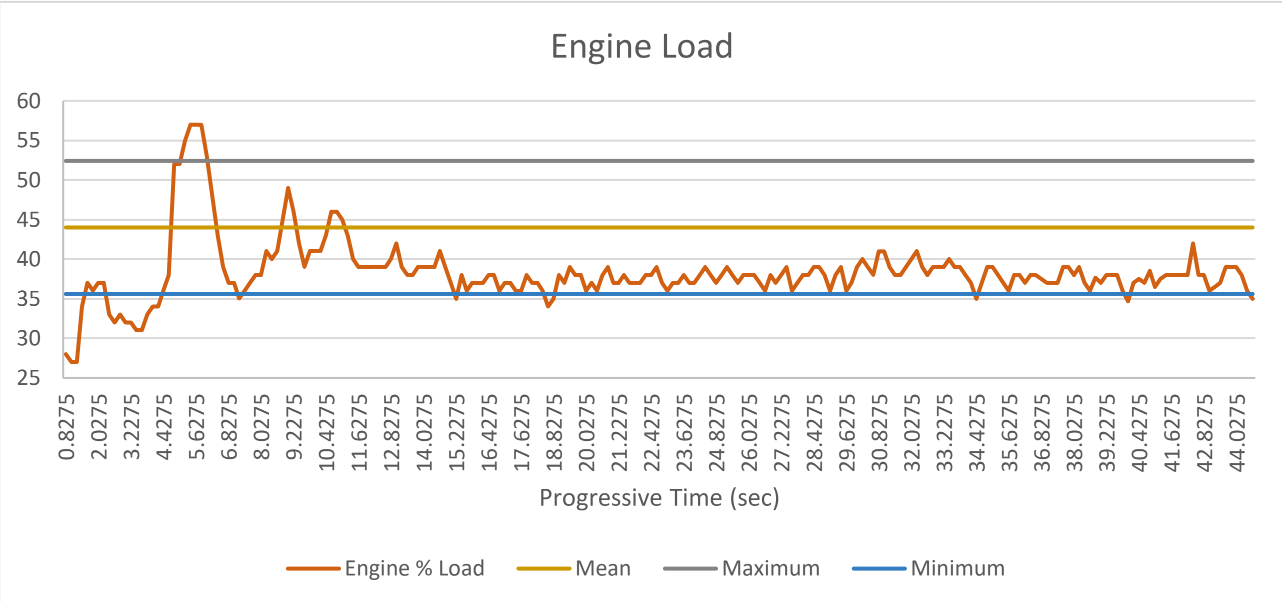

Rear Hitch %
34
32
30
28
26
24
22
20
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1930
1920
1910
1900
1890
1880
1870
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

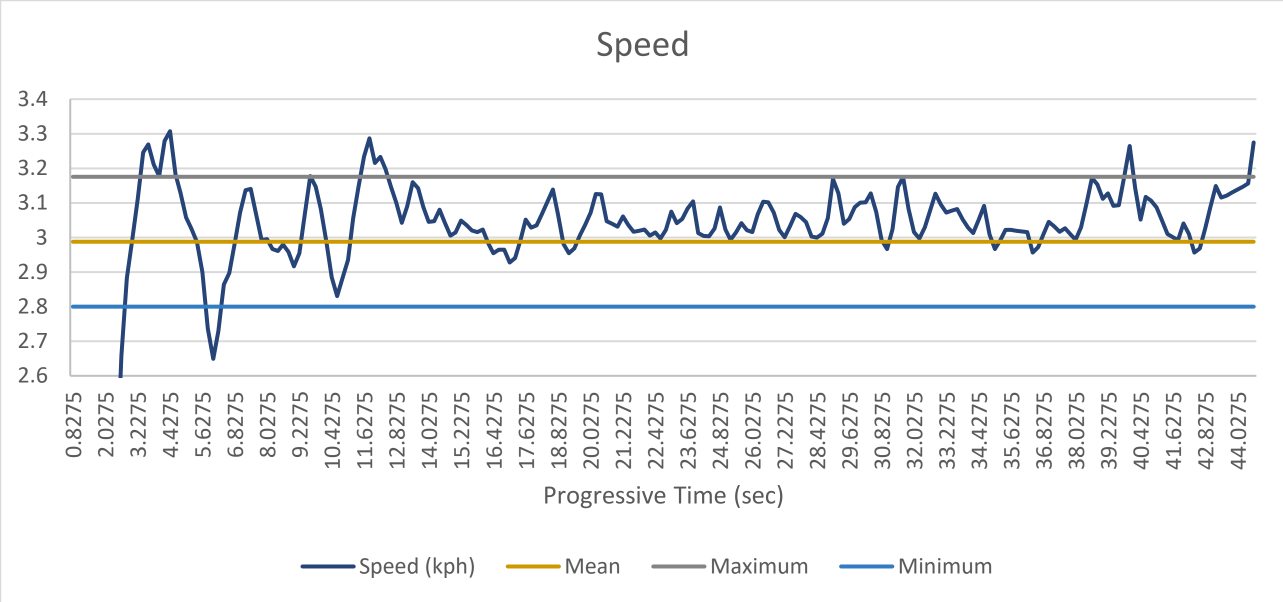
300mm – 3kph

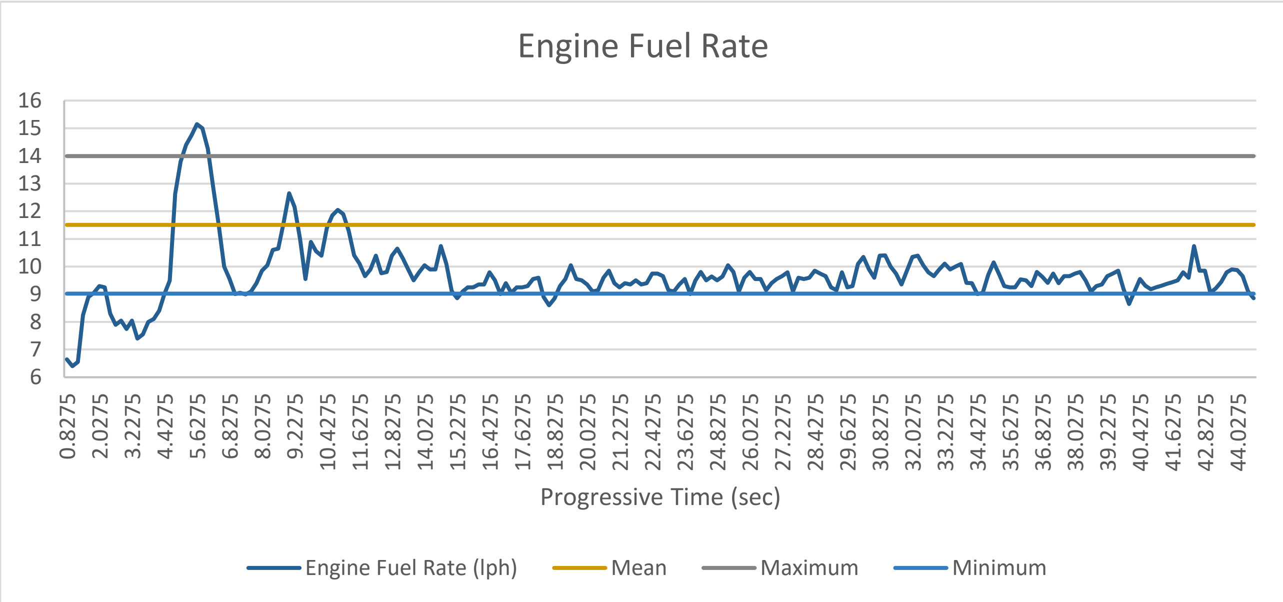


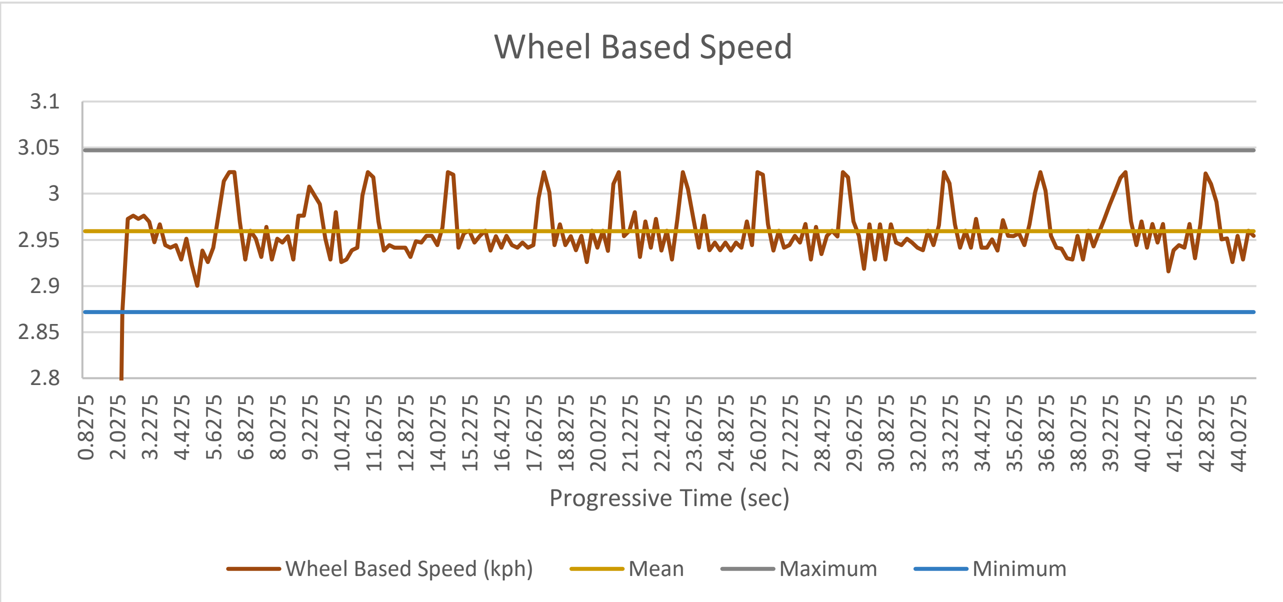
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1930
1920
1910
1900
1890
1880
1870
1860
1850
1840
1830
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

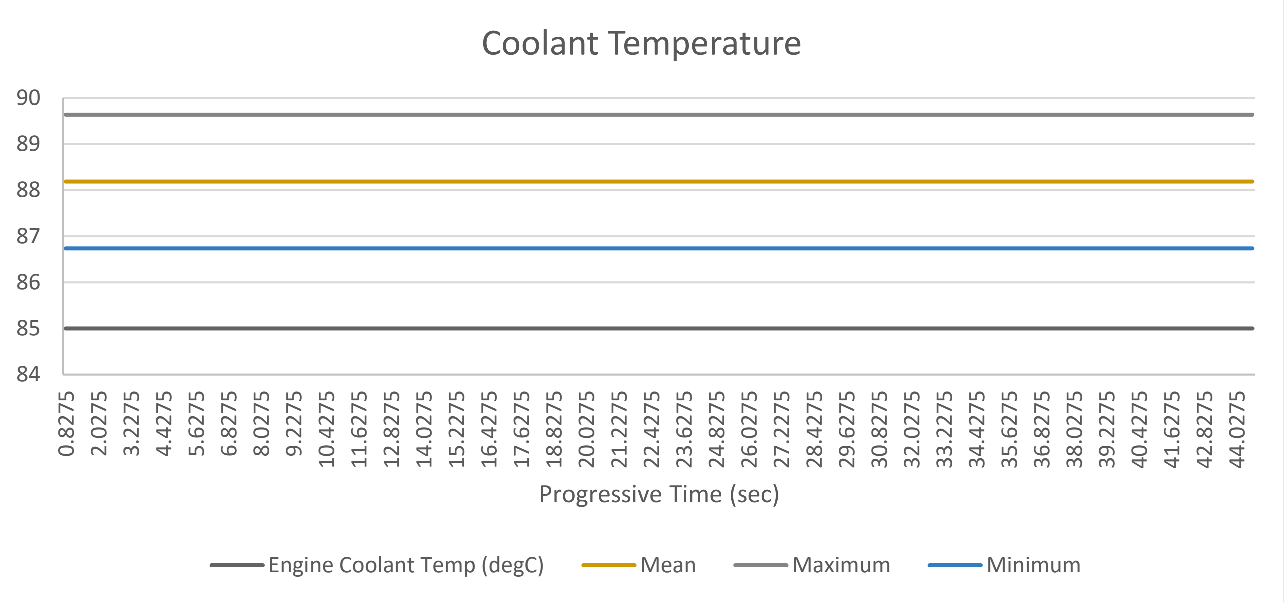


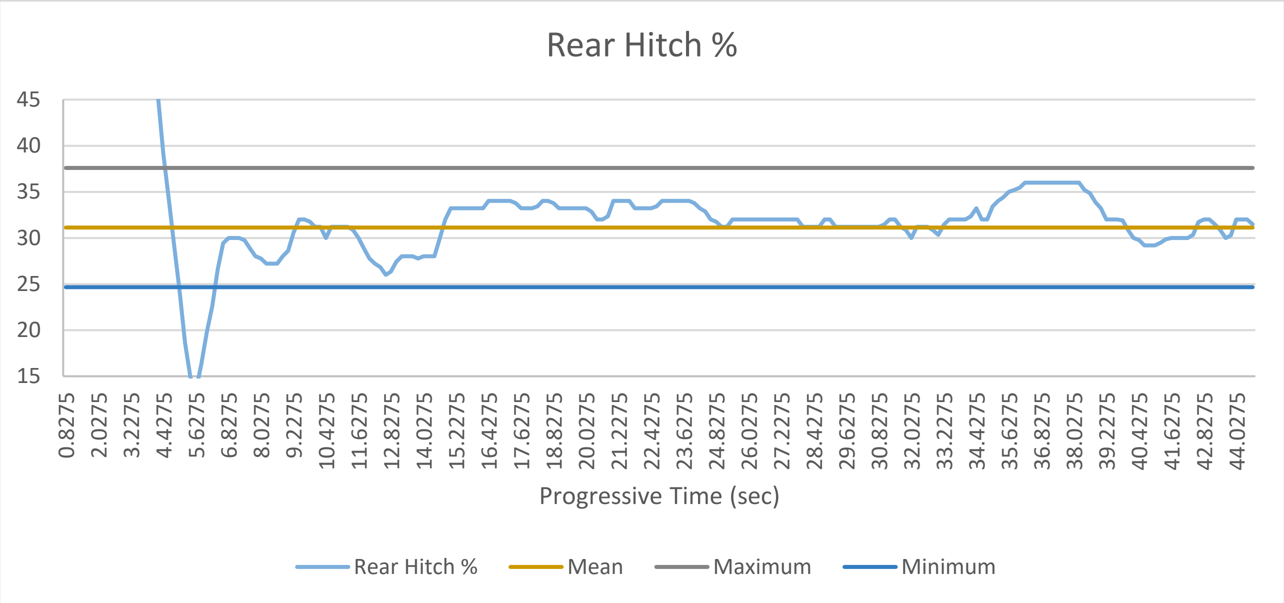
Engine Load
60
55
50
45
40
35
30
25
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

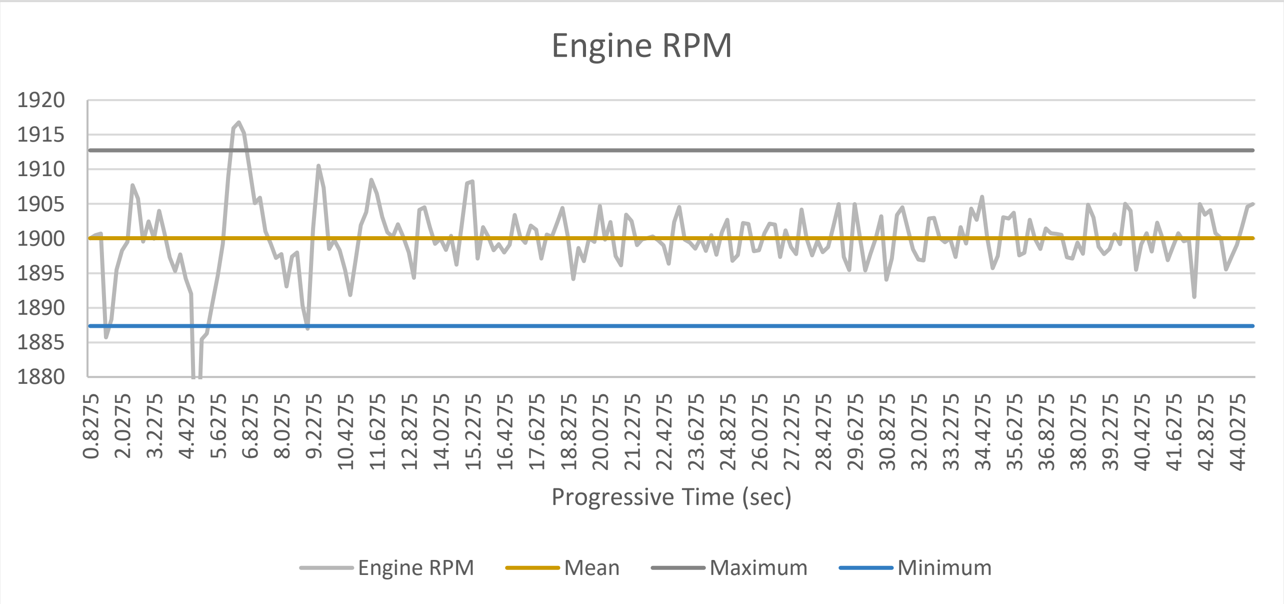

Speed
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

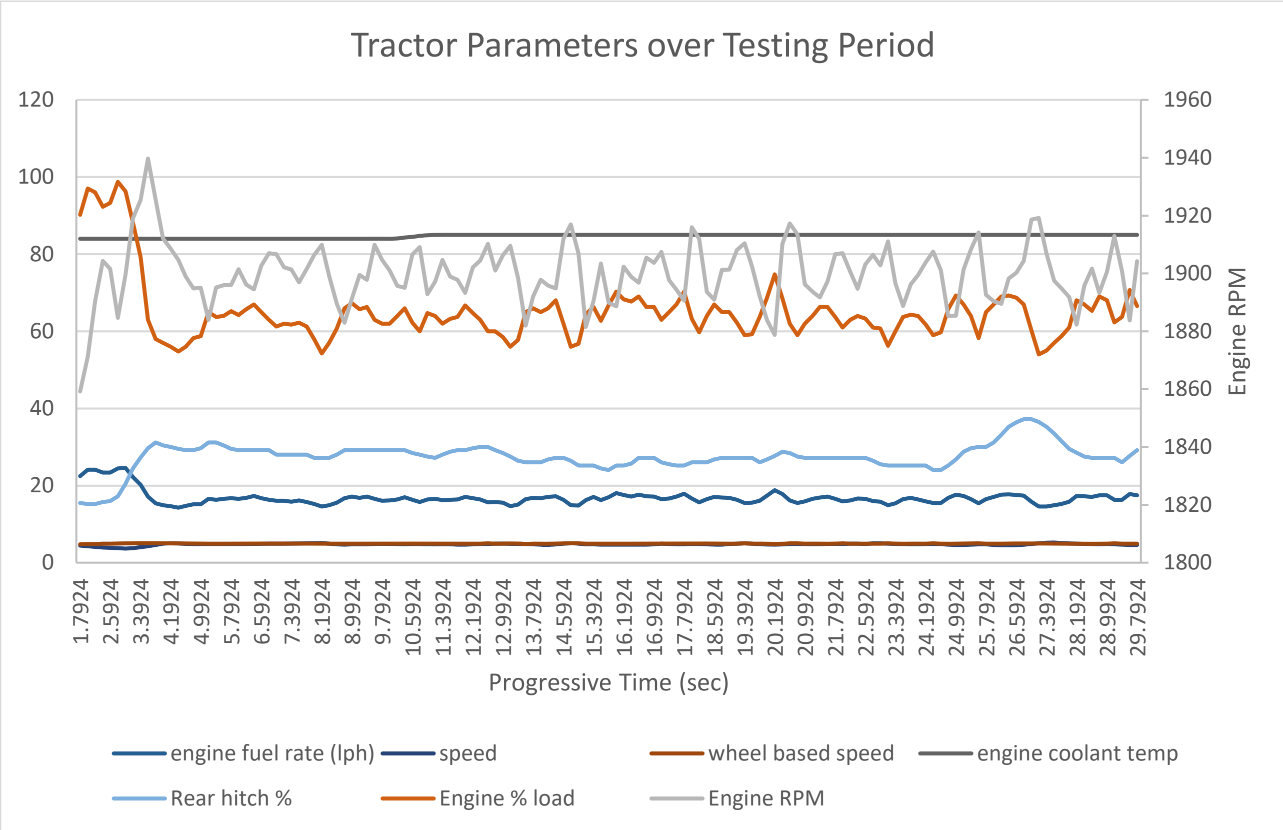

Wheel Based Speed
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
89
88
87
86
85
84
0.8275 2.0275 3.2275 4.4275 5.6275 6.8275 8.0275 9.2275 10.4275 11.6275 12.8275 14.0275 15.2275 16.4275 17.6275 18.8275 20.0275 21.2275 22.4275 23.6275 24.8275 26.0275 27.2275 28.4275 29.6275 30.8275 32.0275 33.2275 34.4275 35.6275 36.8275 38.0275 39.2275 40.4275 41.6275 42.8275 44.0275
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

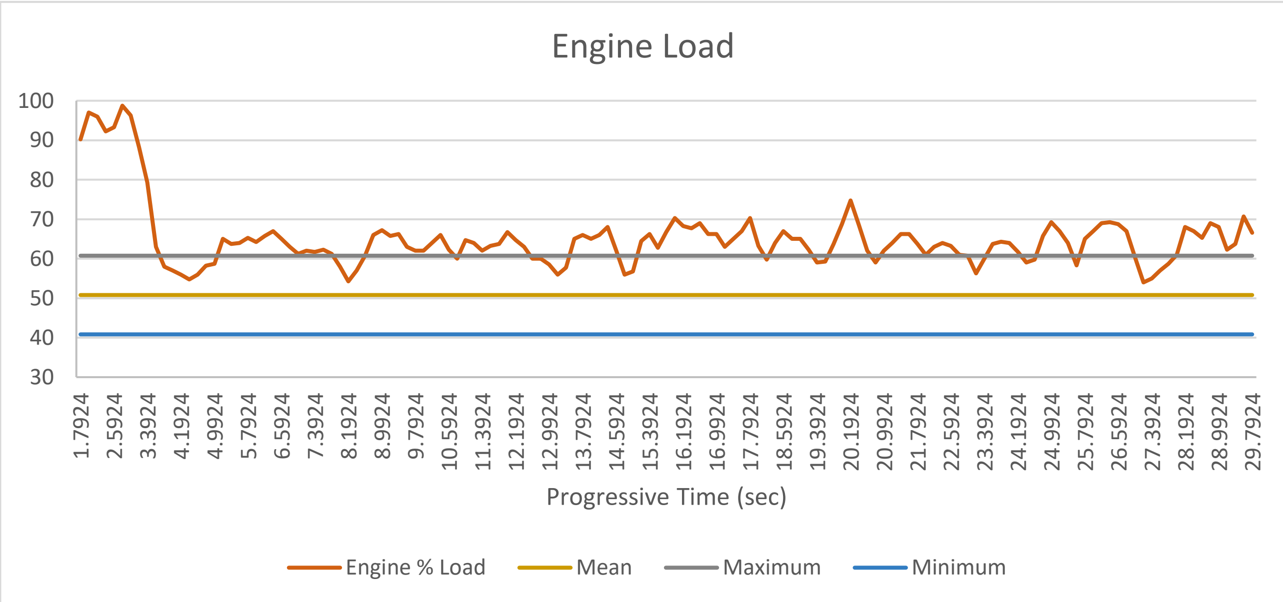

Rear Hitch %
45
40
35
30
25
20
15
0.8275 2.0275 3.2275 4.4275 5.6275 6.8275 8.0275 9.2275 10.4275 11.6275 12.8275 14.0275 15.2275 16.4275 17.6275 18.8275 20.0275 21.2275 22.4275 23.6275 24.8275 26.0275 27.2275 28.4275 29.6275 30.8275 32.0275 33.2275 34.4275 35.6275 36.8275 38.0275 39.2275 40.4275 41.6275 42.8275 44.0275
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1920
1915
1910
1905
1900
1895
1890
1885
1880
0.8275 2.0275 3.2275 4.4275 5.6275 6.8275 8.0275 9.2275 10.4275 11.6275 12.8275 14.0275 15.2275 16.4275 17.6275 18.8275 20.0275 21.2275 22.4275 23.6275 24.8275 26.0275 27.2275 28.4275 29.6275 30.8275 32.0275 33.2275 34.4275 35.6275 36.8275 38.0275 39.2275 40.4275 41.6275 42.8275 44.0275
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

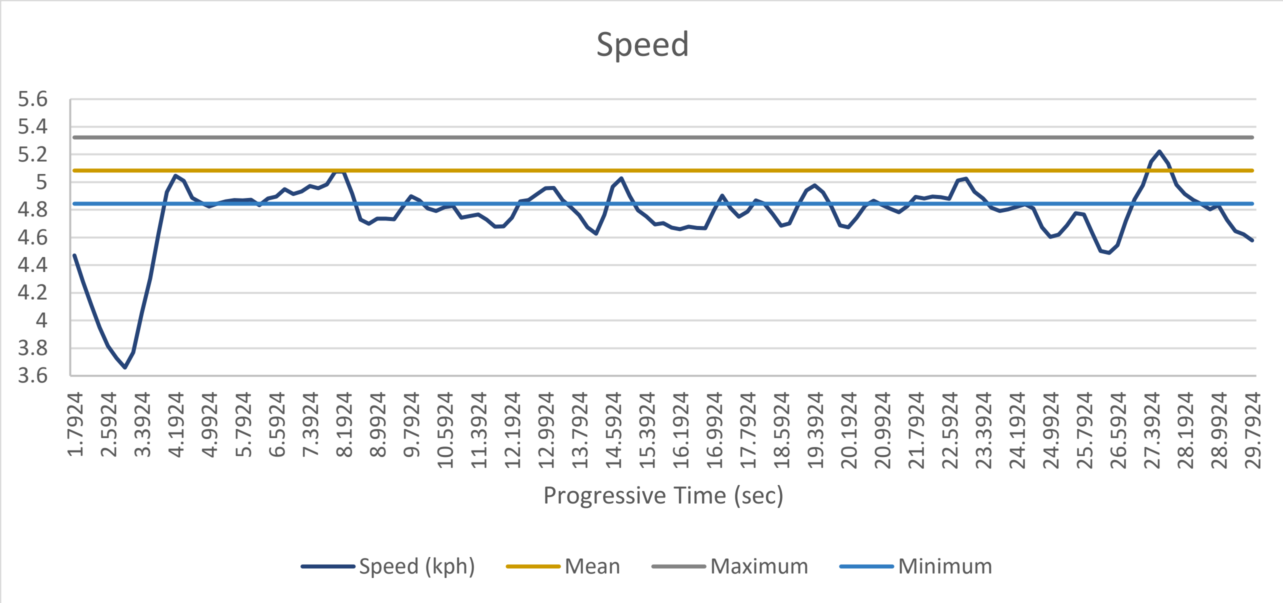
300mm – 5kph

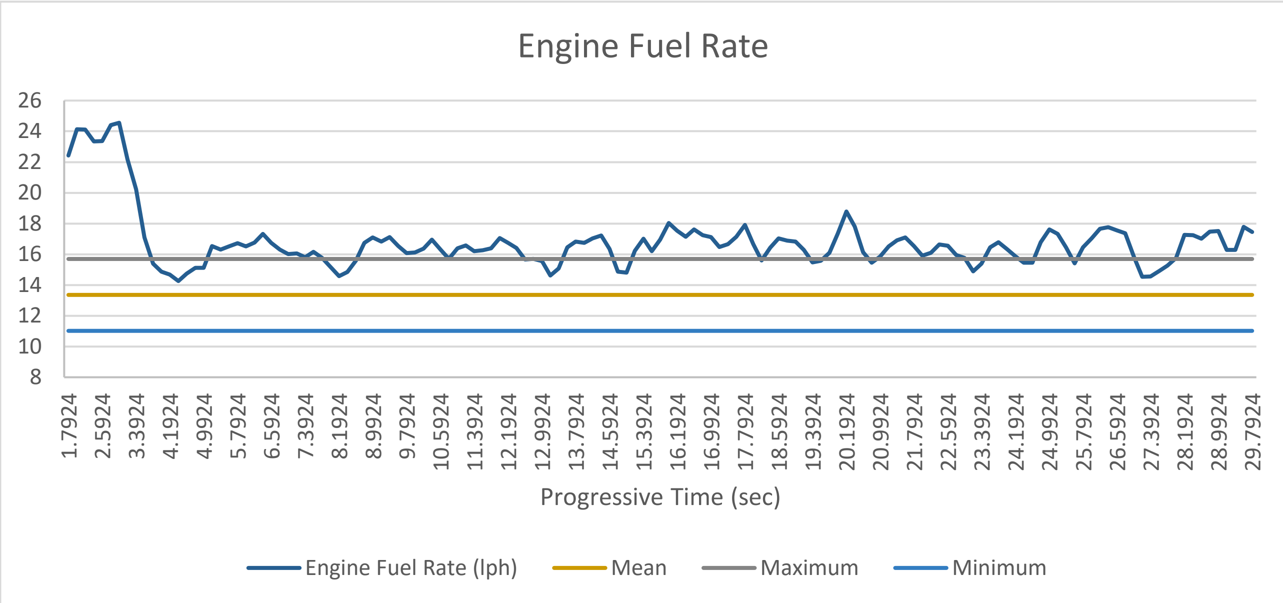


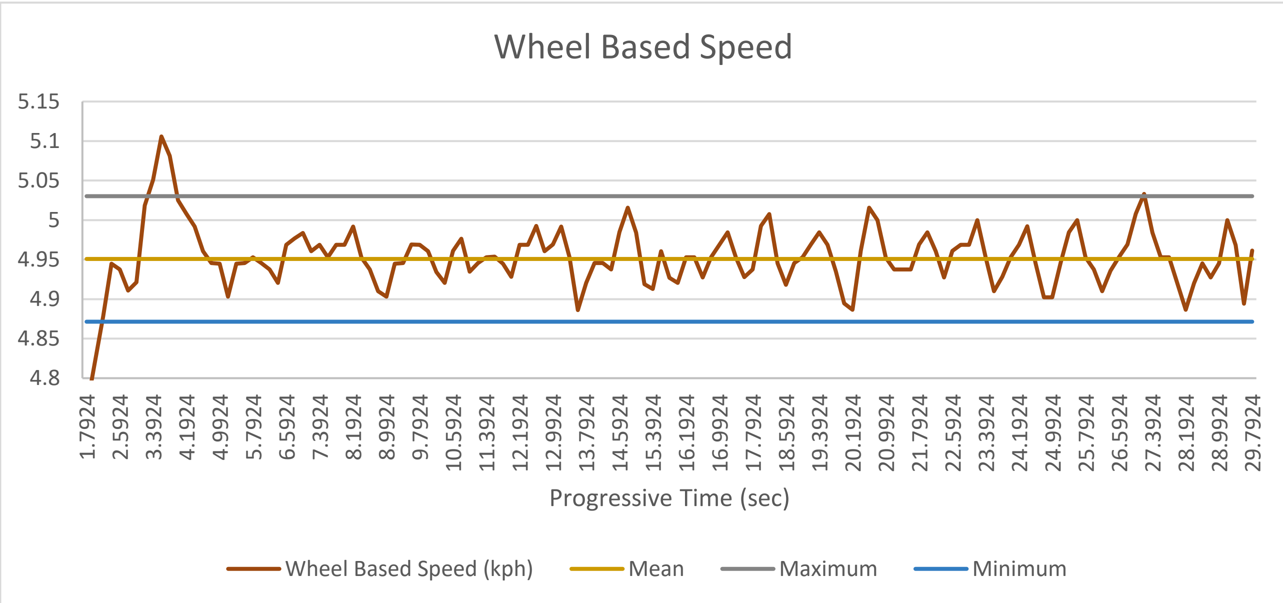
Tractor Parameters over Testing Period
120
100
80
60
40
20
0
1960
1940
1920
1900
1880
1860
1840
1820
1800
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

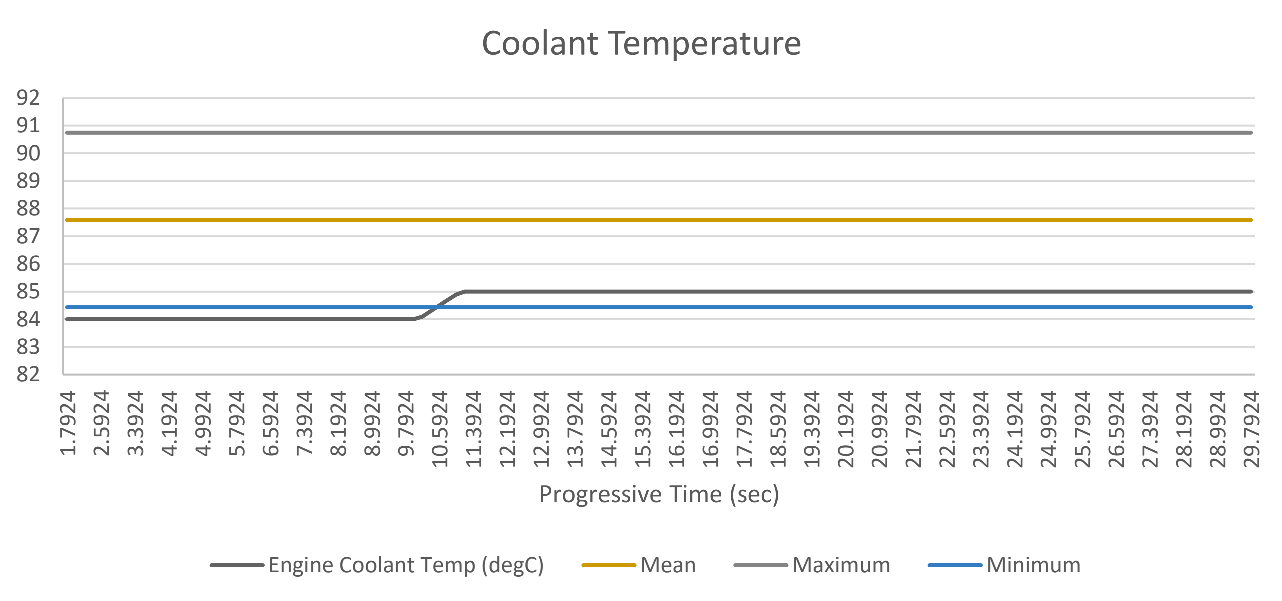


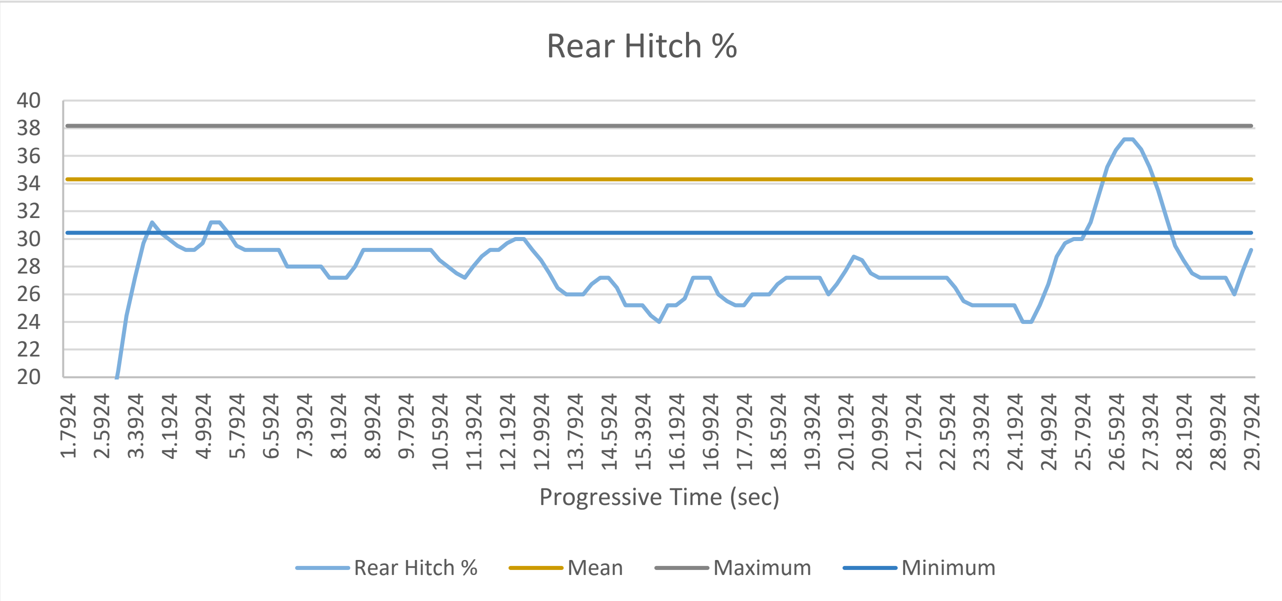
Engine Load
100
90
80
70
60
50
40
30
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

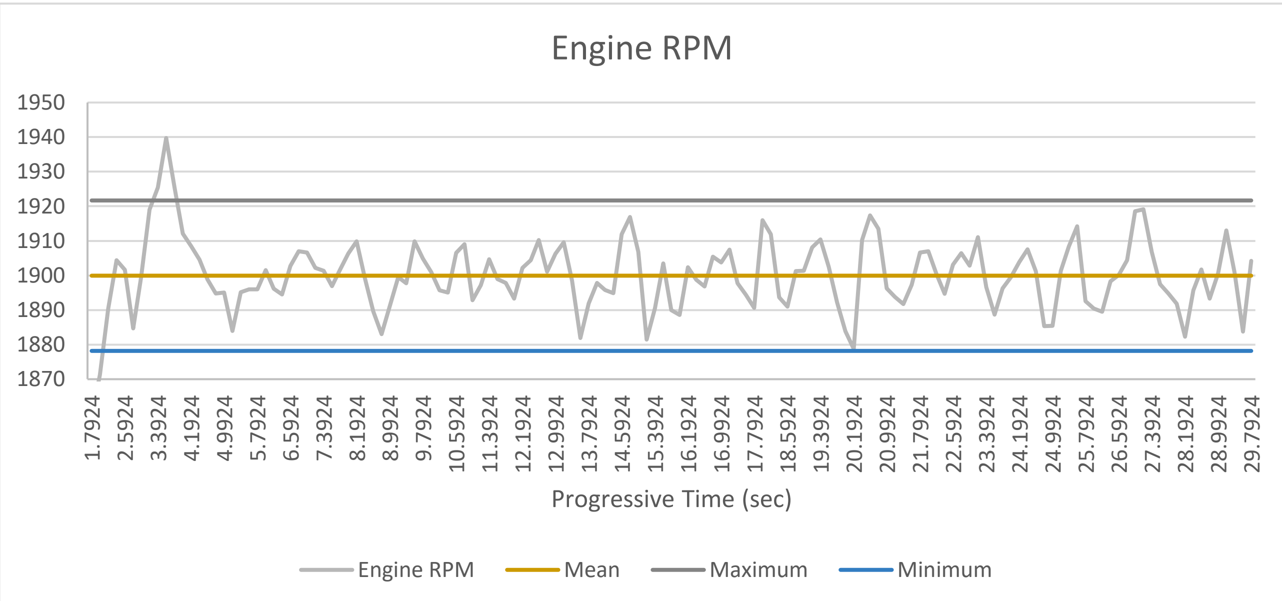

Speed
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
26
24
22
20
18
16
14
12
10
8
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

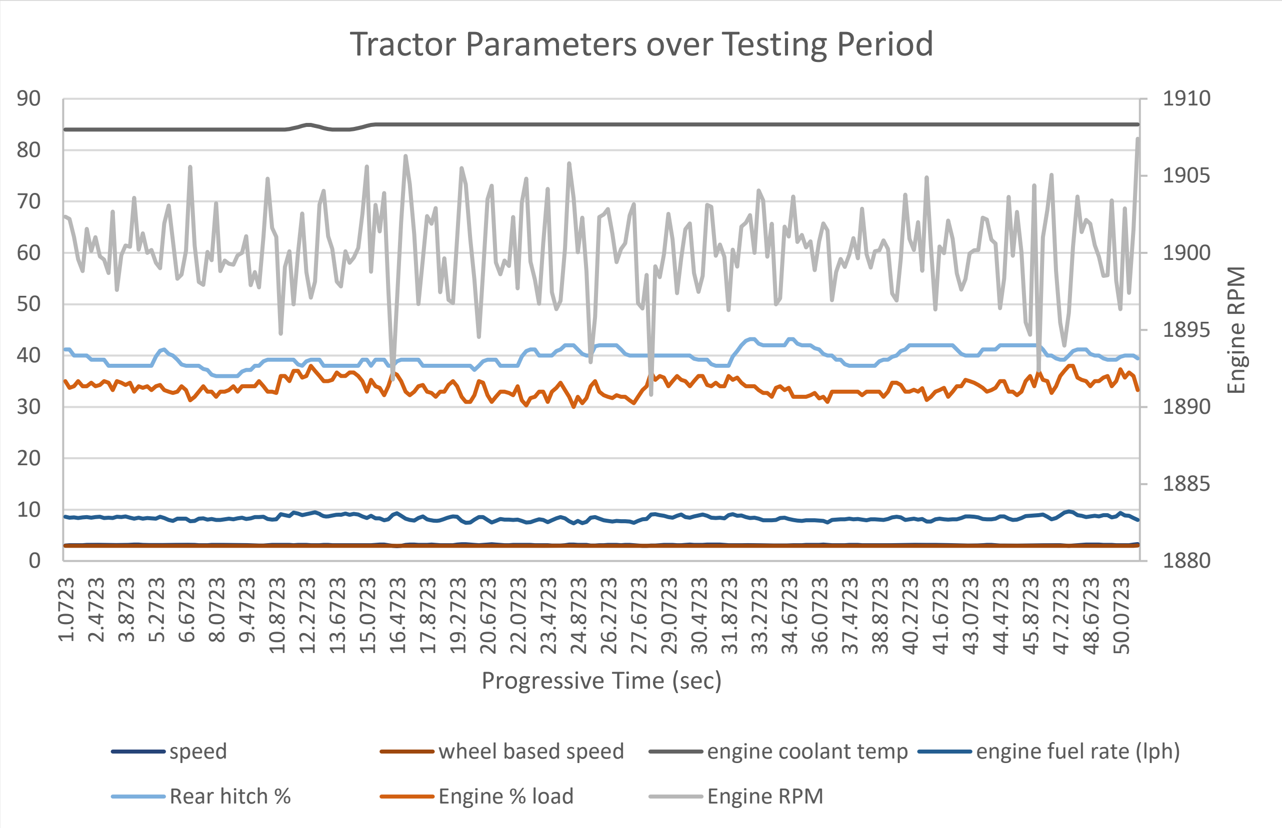

Wheel Based Speed
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
92
91
90
89
88
87
86
85
84
83
82
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

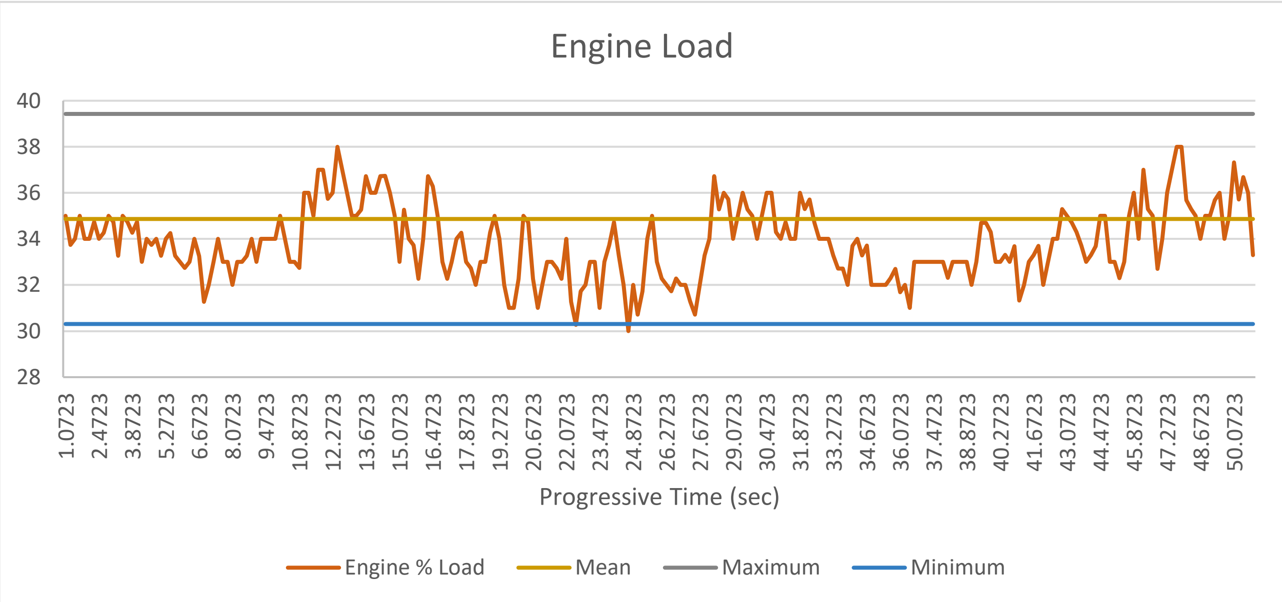

Rear Hitch %
40
38
36
34
32
30
28
26
24
22
20
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1950
1940
1930
1920
1910
1900
1890
1880
1870
1.7924 2.5924 3.3924 4.1924 4.9924 5.7924 6.5924 7.3924 8.1924 8.9924 9.7924 10.5924 11.3924 12.1924 12.9924 13.7924 14.5924 15.3924 16.1924 16.9924 17.7924 18.5924 19.3924 20.1924 20.9924 21.7924 22.5924 23.3924 24.1924 24.9924 25.7924 26.5924 27.3924 28.1924 28.9924 29.7924
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

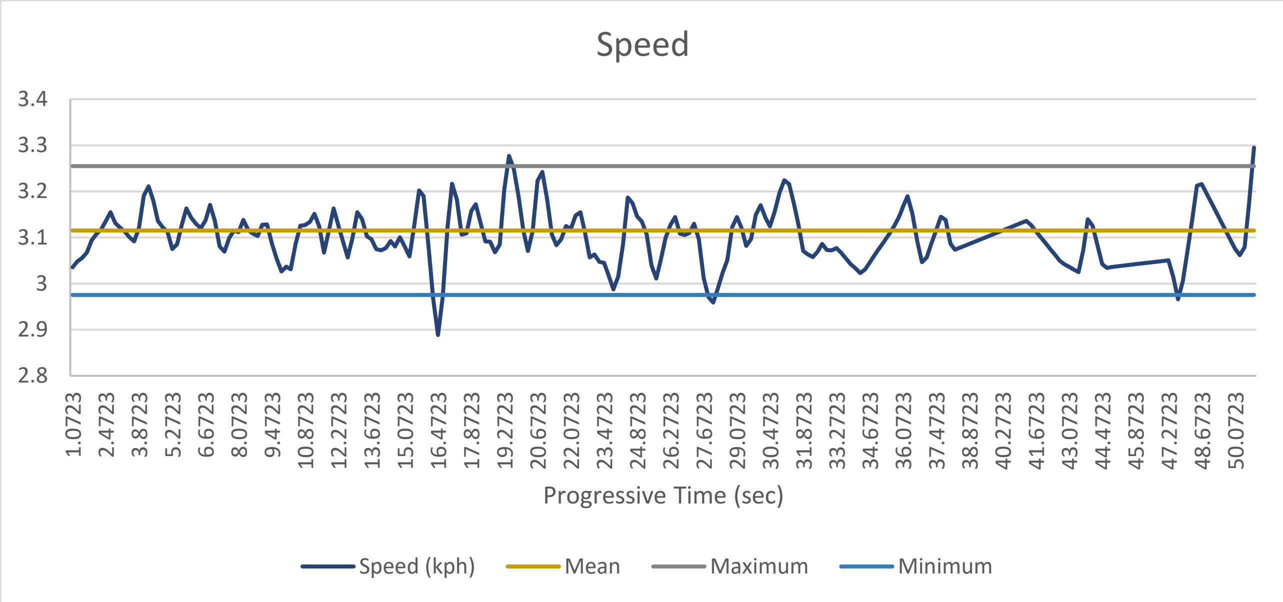
200mm – 3kph

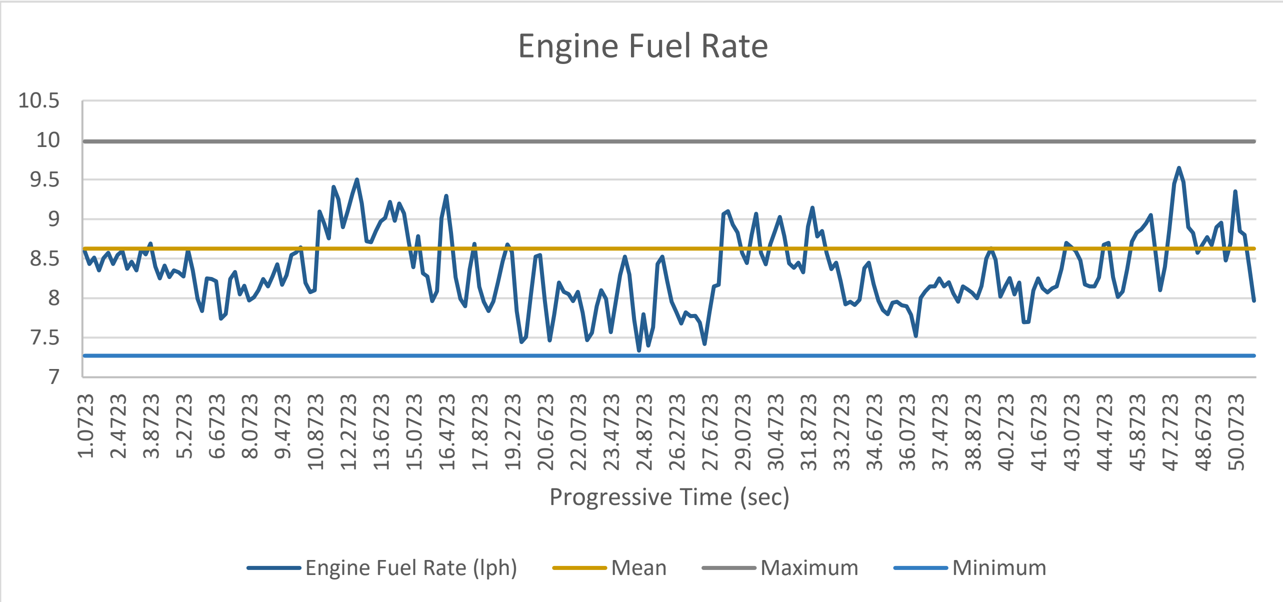


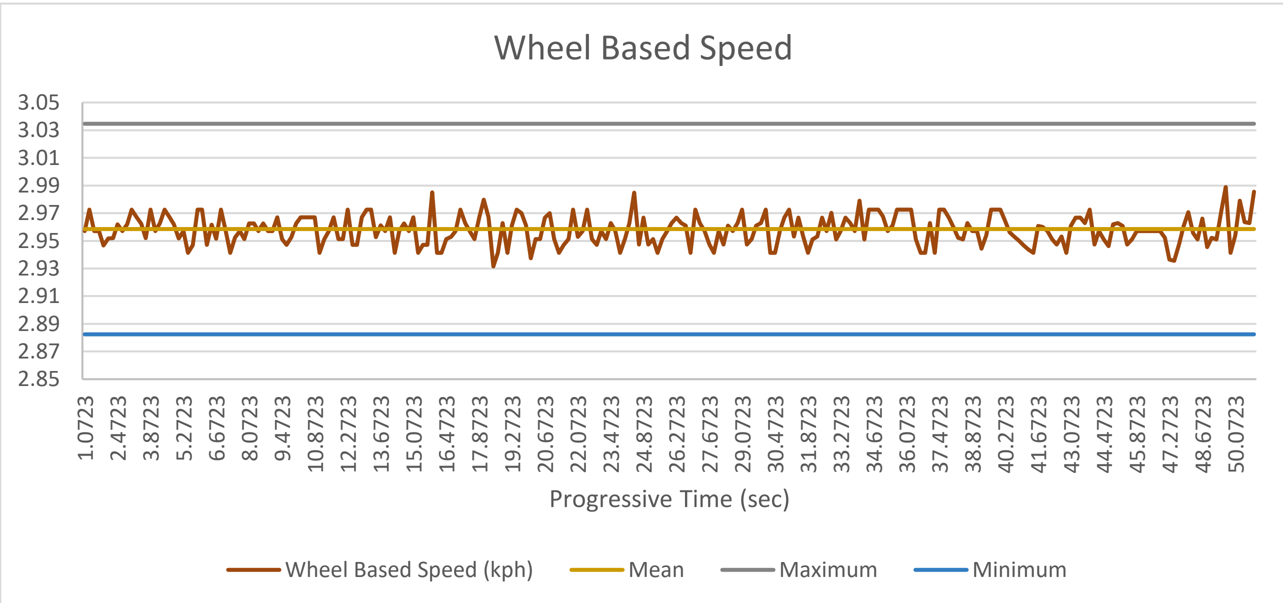
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1910
1905
1900
1895
1890
1885
1880
Engine RPM
1.0723
2.4723
3.8723
5.2723
6.6723
8.0723
9.4723
10.8723
12.2723
13.6723
15.0723
16.4723
17.8723
19.2723
20.6723
22.0723
23.4723
24.8723
26.2723
27.6723
29.0723
30.4723
31.8723
33.2723
34.6723
36.0723
37.4723
38.8723
40.2723
41.6723
43.0723
44.4723
45.8723
47.2723
48.6723
50.0723
Progressive Time (sec)
speed
wheel based speed
engine coolant temp
engine fuel rate (lph)
Rear hitch %
Engine % load
Engine RPM

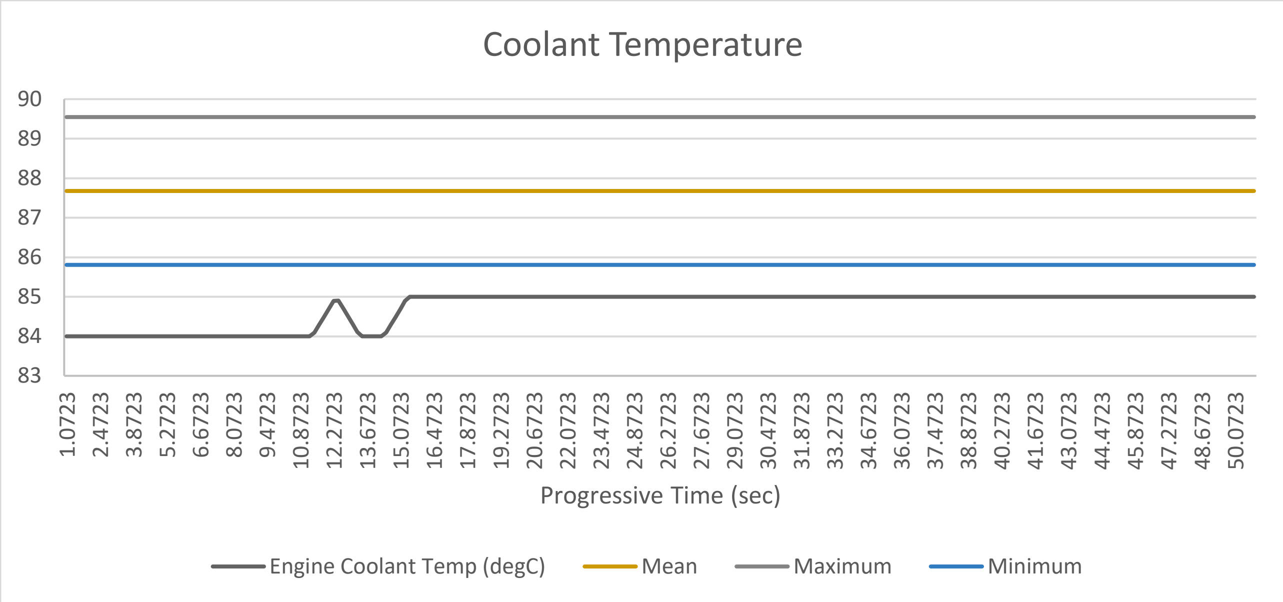


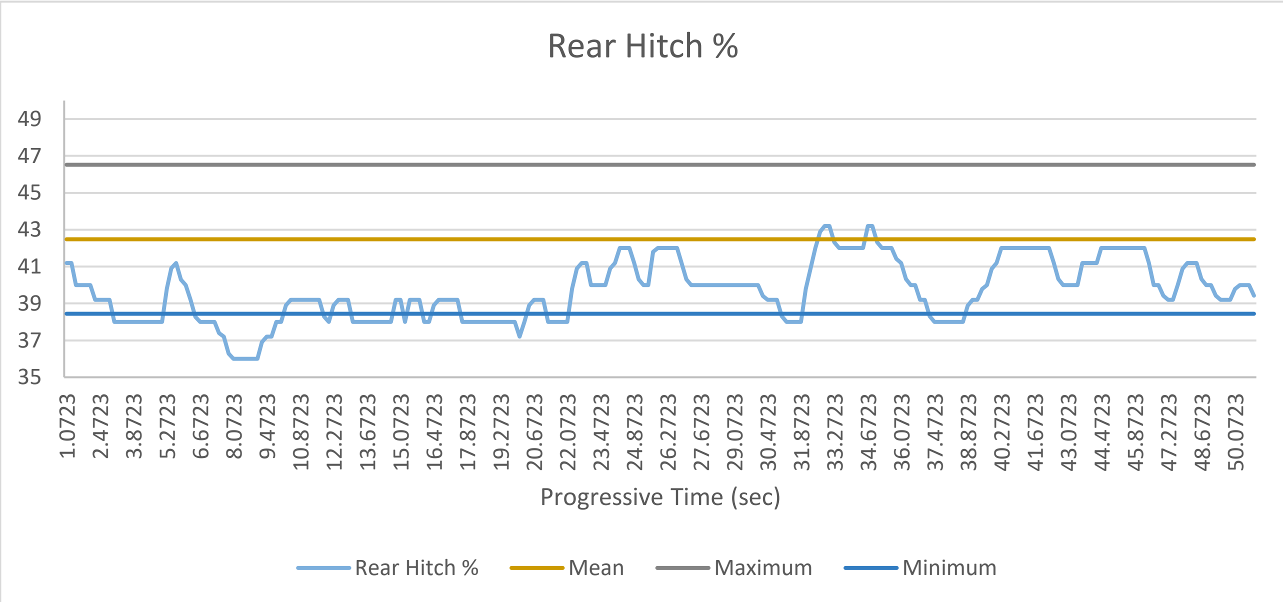
Engine Load
40
38
36
34
32
30
28
1.0723
2.4723
3.8723
5.2723
6.6723
8.0723
9.4723
10.8723
12.2723
13.6723
15.0723
16.4723
17.8723
19.2723
20.6723
22.0723
23.4723
24.8723
26.2723
27.6723
29.0723
30.4723
31.8723
33.2723
34.6723
36.0723
37.4723
38.8723
40.2723
41.6723
43.0723
44.4723
45.8723
47.2723
48.6723
50.0723
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

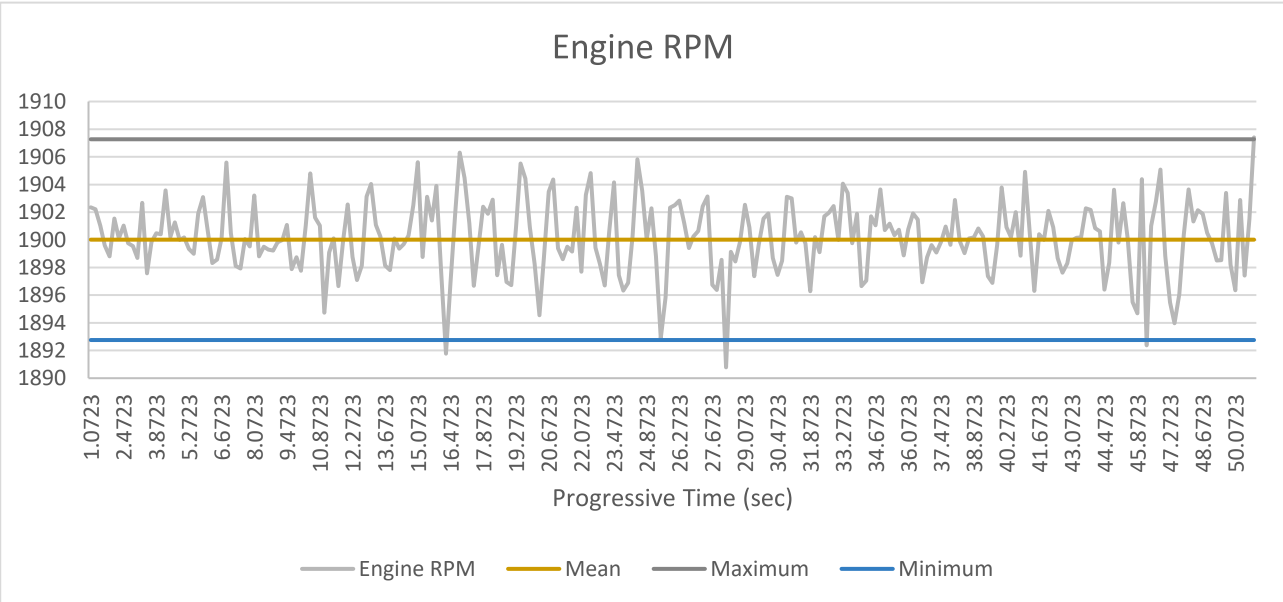

Speed
3.4
3.3
3.2
3.1
3
2.9
2.8
1.0723 2.4723 3.8723 5.2723 6.6723 8.0723 9.4723 10.8723 12.2723 13.6723 15.0723 16.4723 17.8723 19.2723 20.6723 22.0723 23.4723 24.8723 26.2723 27.6723 29.0723 30.4723 31.8723 33.2723 34.6723 36.0723 37.4723 38.8723 40.2723 41.6723 43.0723 44.4723 45.8723 47.2723 48.6723 50.0723
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
10.5
10
9.5
9
8.5
8
7.5
7
1.0723 2.4723 3.8723 5.2723 6.6723 8.0723 9.4723 10.8723 12.2723 13.6723 15.0723 16.4723 17.8723 19.2723 20.6723 22.0723 23.4723 24.8723 26.2723 27.6723 29.0723 30.4723 31.8723 33.2723 34.6723 36.0723 37.4723 38.8723 40.2723 41.6723 43.0723 44.4723 45.8723 47.2723 48.6723 50.0723
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

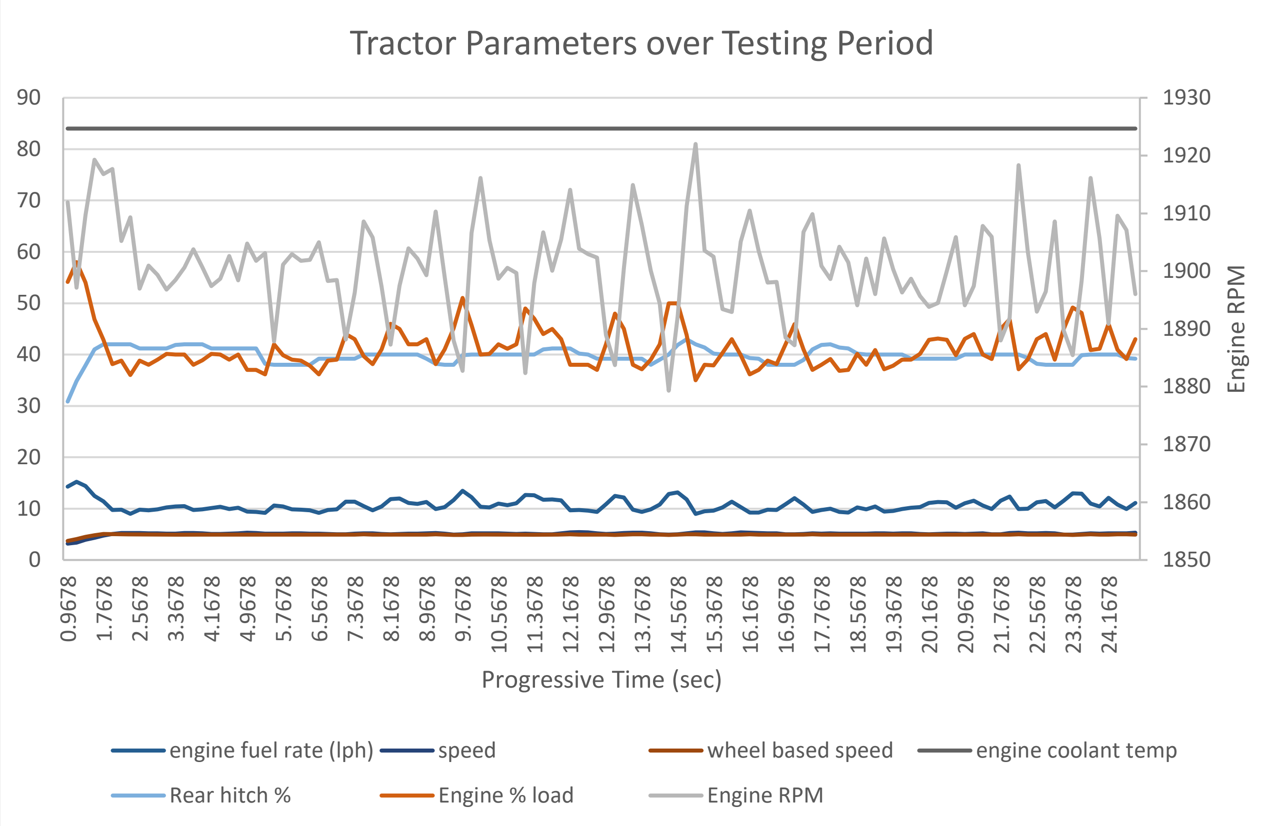

Wheel Based Speed
3.05
3.03
3.01
2.99
2.97
2.95
2.93
2.91
2.89
2.87
2.85
1.0723 2.4723 3.8723 5.2723 6.6723 8.0723 9.4723 10.8723 12.2723 13.6723 15.0723 16.4723 17.8723 19.2723 20.6723 22.0723 23.4723 24.8723 26.2723 27.6723 29.0723 30.4723 31.8723 33.2723 34.6723 36.0723 37.4723 38.8723 40.2723 41.6723 43.0723 44.4723 45.8723 47.2723 48.6723 50.0723
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

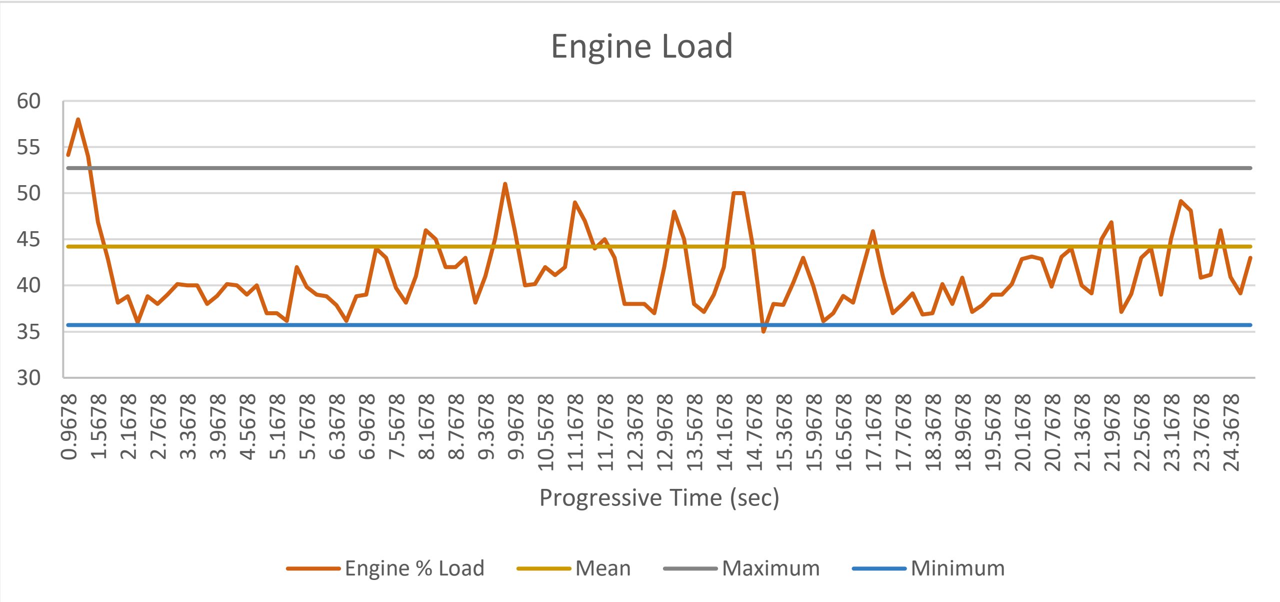

Coolant Temperature
90
89
88
87
86
85
84
83
1.0723
2.4723
3.8723
5.2723
6.6723
8.0723
9.4723
10.8723
12.2723
13.6723
15.0723
16.4723
17.8723
19.2723
20.6723
22.0723
23.4723
24.8723
26.2723
27.6723
29.0723
30.4723
31.8723
33.2723
34.6723
36.0723
37.4723
38.8723
40.2723
41.6723
43.0723
44.4723
45.8723
47.2723
48.6723
50.0723
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

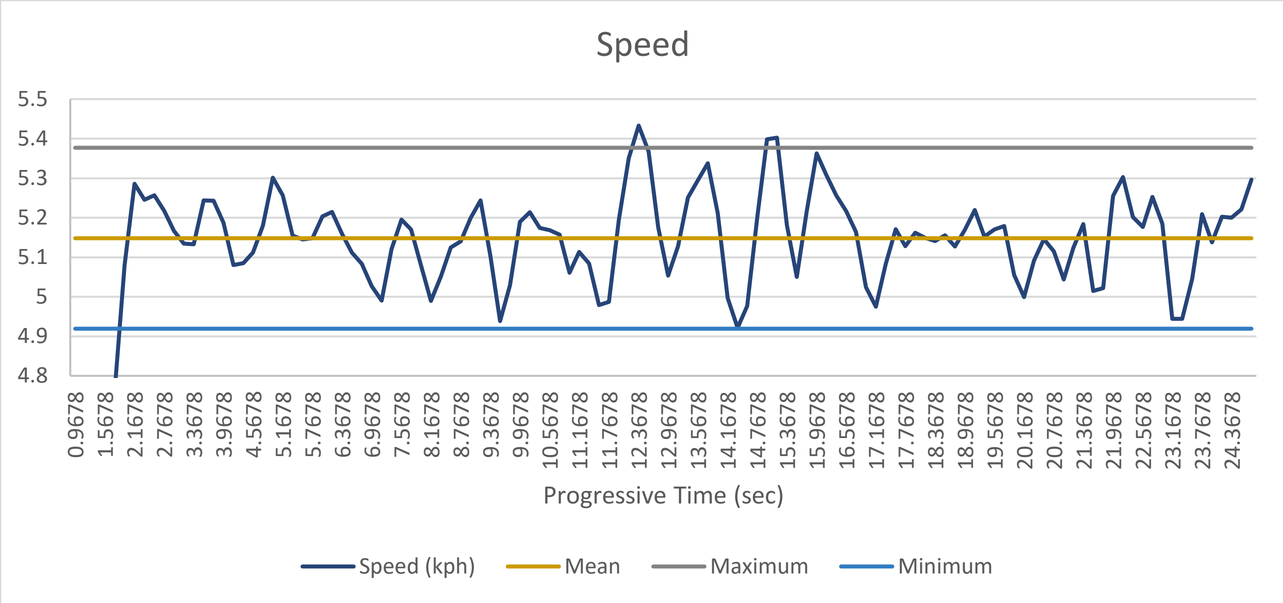

Rear Hitch %
49
47
45
43
41
39
37
35
1.0723
2.4723
3.8723
5.2723
6.6723
8.0723
9.4723
10.8723
12.2723
13.6723
15.0723
16.4723
17.8723
19.2723
20.6723
22.0723
23.4723
24.8723
26.2723
27.6723
29.0723
30.4723
31.8723
33.2723
34.6723
36.0723
37.4723
38.8723
40.2723
41.6723
43.0723
44.4723
45.8723
47.2723
48.6723
50.0723
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

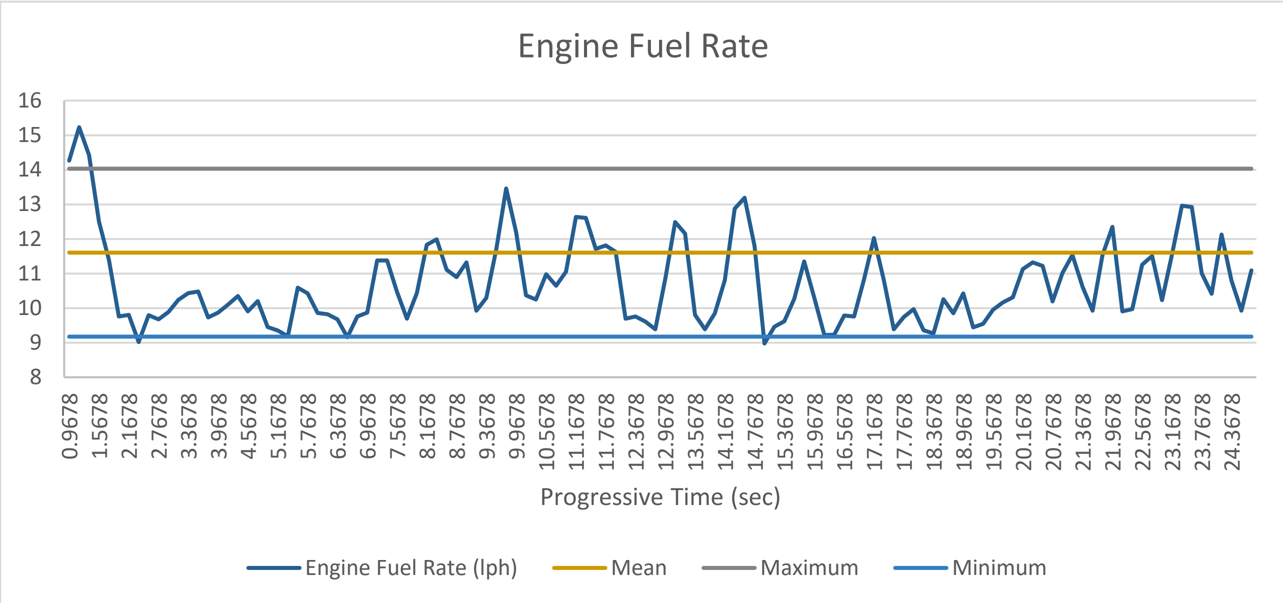

Engine RPM
1910
1908
1906
1904
1902
1900
1898
1896
1894
1892
1890
1.0723
2.4723
3.8723
5.2723
6.6723
8.0723
9.4723
10.8723
12.2723
13.6723
15.0723
16.4723
17.8723
19.2723
20.6723
22.0723
23.4723
24.8723
26.2723
27.6723
29.0723
30.4723
31.8723
33.2723
34.6723
36.0723
37.4723
38.8723
40.2723
41.6723
43.0723
44.4723
45.8723
47.2723
48.6723
50.0723
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

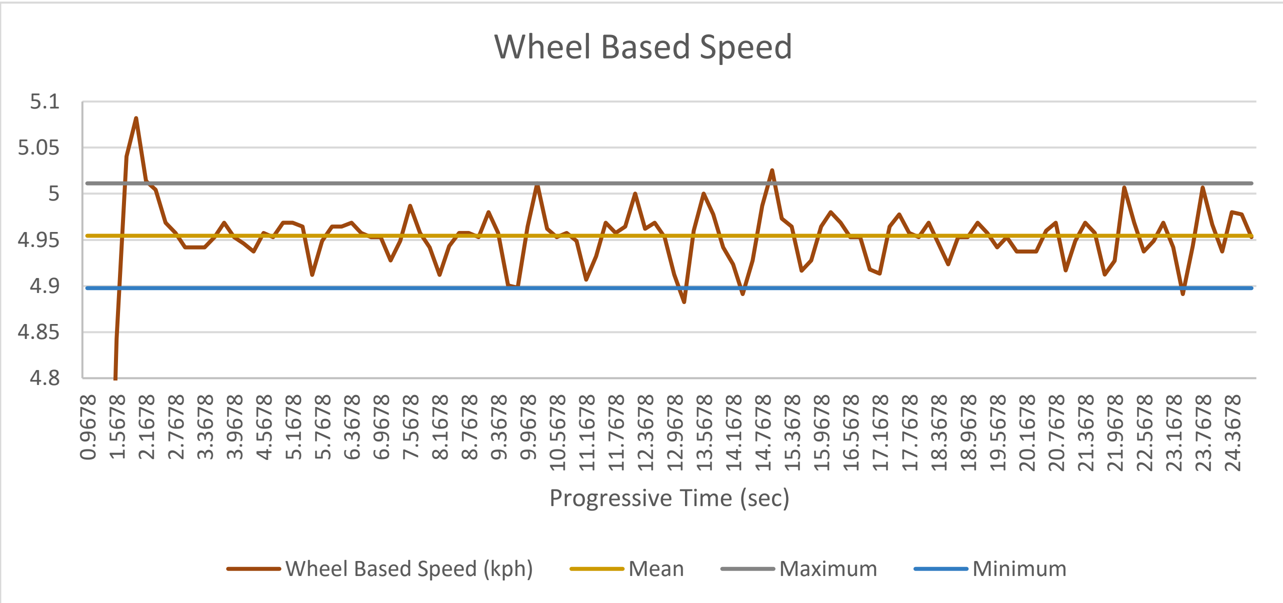
200mm – 5kph

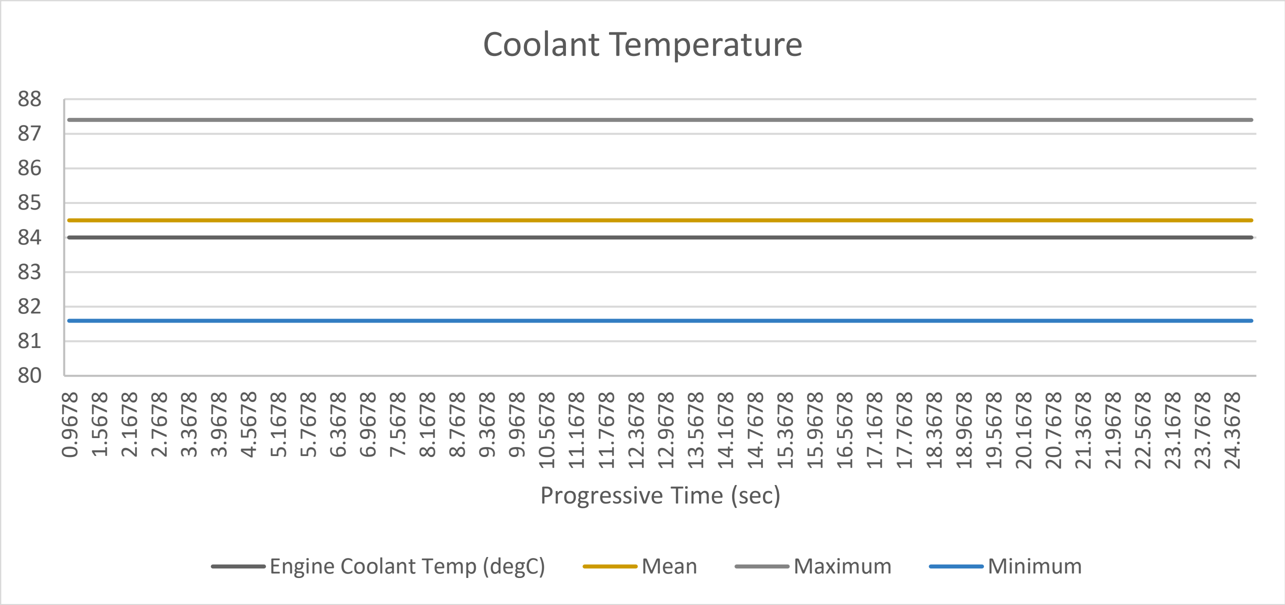

Tractor Parameters over Testing Period
Engine RPM
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

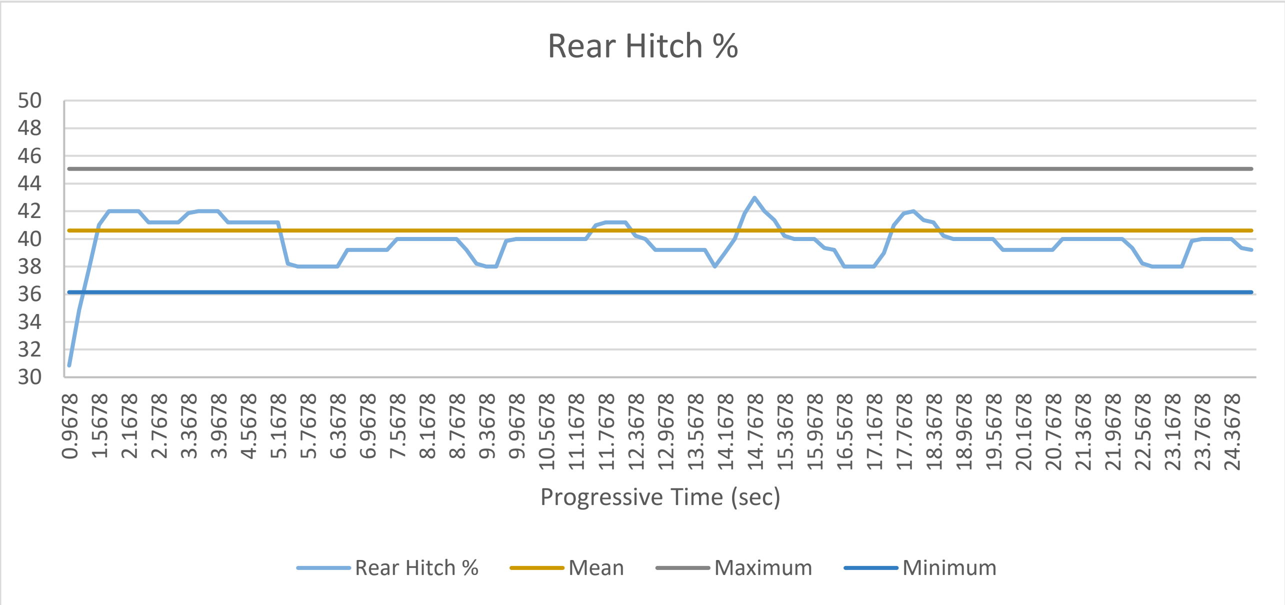

Engine Load
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

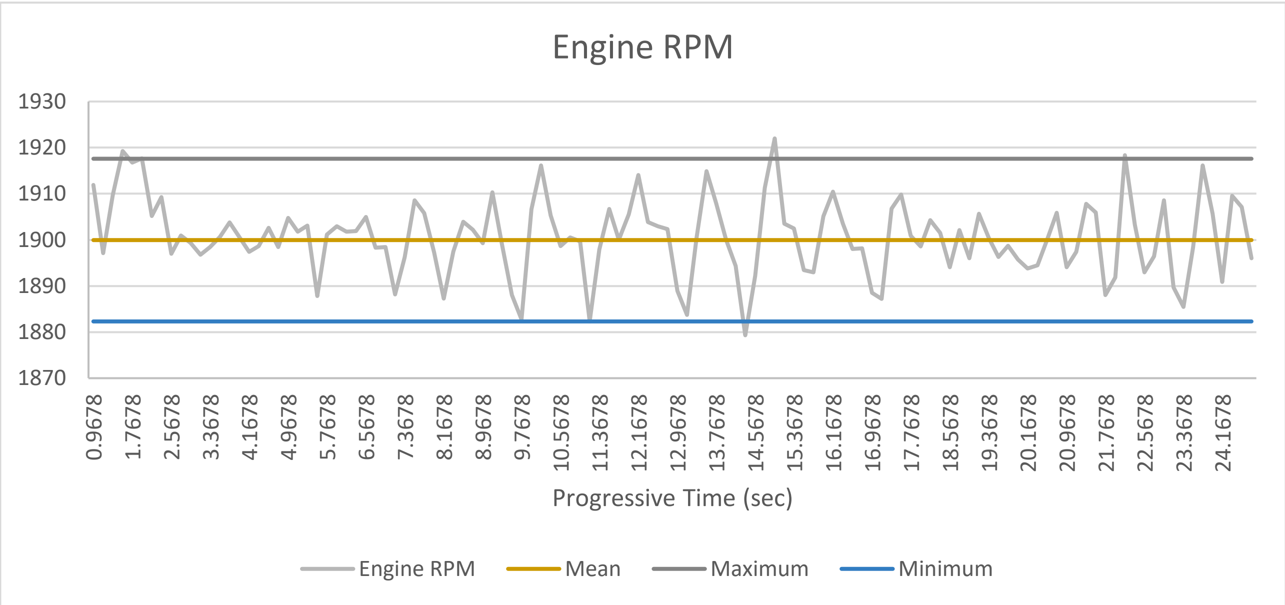

Speed
5.5
5.4
5.3
5.2
5.1
5
4.9
4.8
0.9678
1.5678
2.1678
2.7678
3.3678
3.9678
4.5678
5.1678
5.7678
6.3678
6.9678
7.5678
8.1678
8.7678
9.3678
9.9678
10.5678
11.1678
11.7678
12.3678
12.9678
13.5678
14.1678
14.7678
15.3678
15.9678
16.5678
17.1678
17.7678
18.3678
18.9678
19.5678
20.1678
20.7678
21.3678
21.9678
22.5678
23.1678
23.7678
24.3678
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
16
15
14
13
12
11
10
9
8
0.9678
1.5678
2.1678
2.7678
3.3678
3.9678
4.5678
5.1678
5.7678
6.3678
6.9678
7.5678
8.1678
8.7678
9.3678
9.9678
10.5678
11.1678
11.7678
12.3678
12.9678
13.5678
14.1678
14.7678
15.3678
15.9678
16.5678
17.1678
17.7678
18.3678
18.9678
19.5678
20.1678
20.7678
21.3678
21.9678
22.5678
23.1678
23.7678
24.3678
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
5.1
5.05
5
4.95
4.9
4.85
4.8
0.9678
1.5678
2.1678
2.7678
3.3678
3.9678
4.5678
5.1678
5.7678
6.3678
6.9678
7.5678
8.1678
8.7678
9.3678
9.9678
10.5678
11.1678
11.7678
12.3678
12.9678
13.5678
14.1678
14.7678
15.3678
15.9678
16.5678
17.1678
17.7678
18.3678
18.9678
19.5678
20.1678
20.7678
21.3678
21.9678
22.5678
23.1678
23.7678
24.3678
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

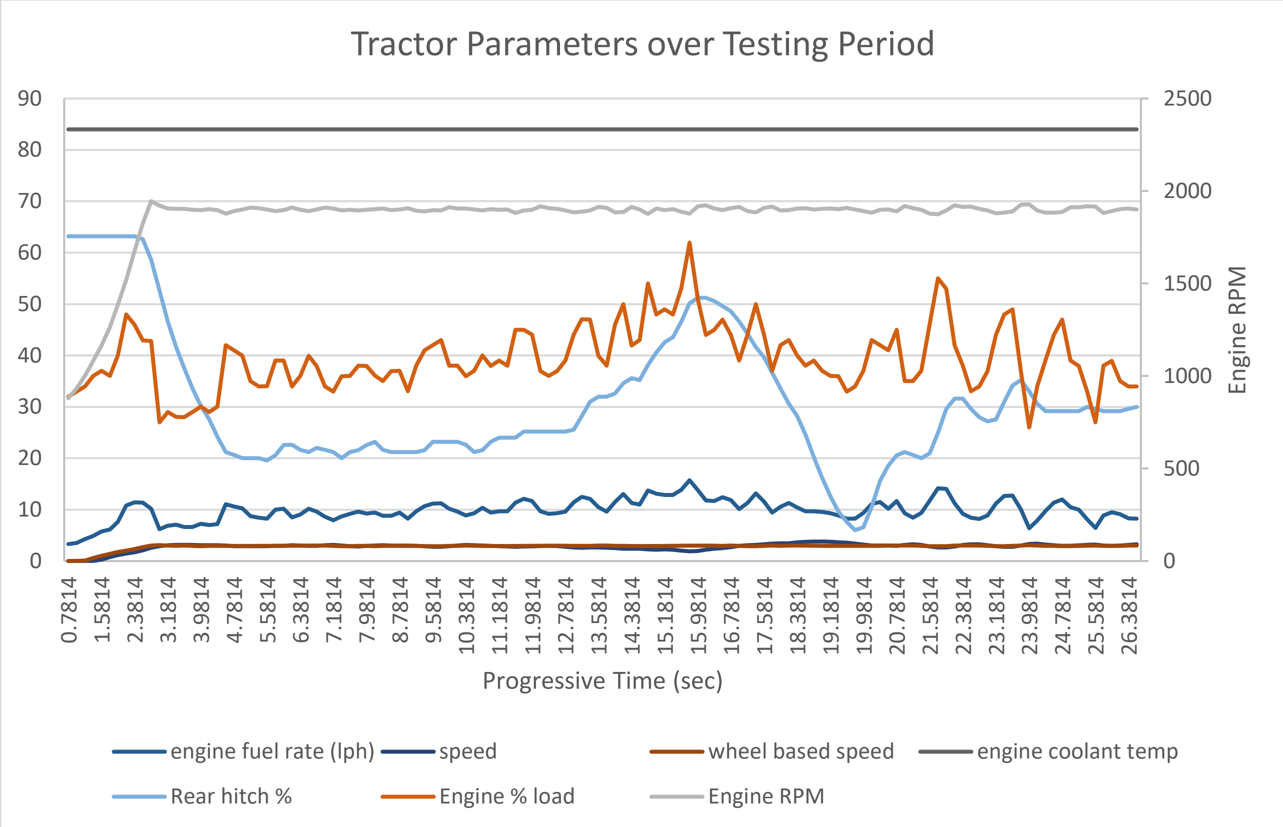

Coolant Temperature
88
87
86
85
84
83
82
81
80
0.9678
1.5678
2.1678
2.7678
3.3678
3.9678
4.5678
5.1678
5.7678
6.3678
6.9678
7.5678
8.1678
8.7678
9.3678
9.9678
10.5678
11.1678
11.7678
12.3678
12.9678
13.5678
14.1678
14.7678
15.3678
15.9678
16.5678
17.1678
17.7678
18.3678
18.9678
19.5678
20.1678
20.7678
21.3678
21.9678
22.5678
23.1678
23.7678
24.3678
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

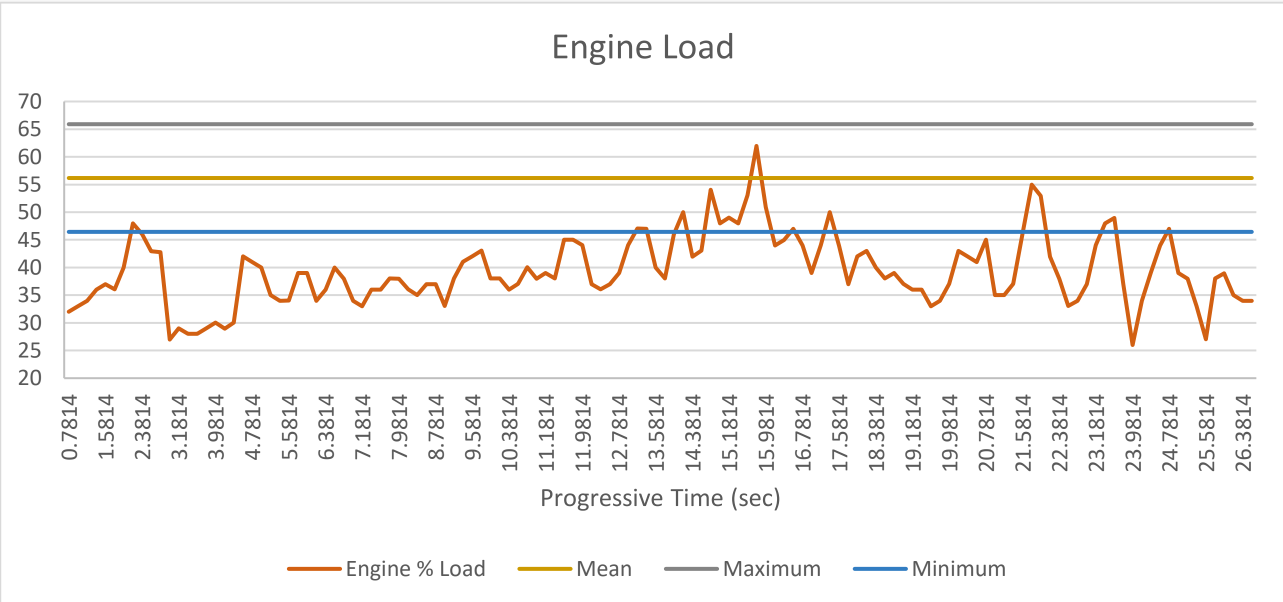

Rear Hitch %
50
48
46
44
42
40
38
36
34
32
30
0.9678
1.5678
2.1678
2.7678
3.3678
3.9678
4.5678
5.1678
5.7678
6.3678
6.9678
7.5678
8.1678
8.7678
9.3678
9.9678
10.5678
11.1678
11.7678
12.3678
12.9678
13.5678
14.1678
14.7678
15.3678
15.9678
16.5678
17.1678
17.7678
18.3678
18.9678
19.5678
20.1678
20.7678
21.3678
21.9678
22.5678
23.1678
23.7678
24.3678
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

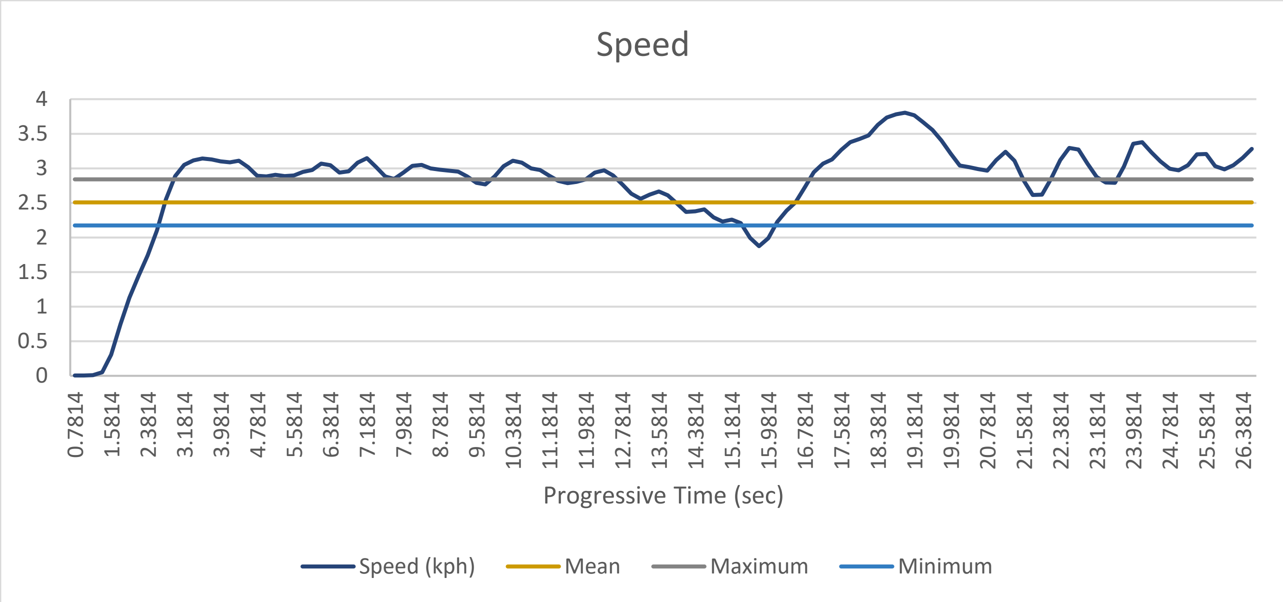

Engine RPM
1930
1920
1910
1900
1890
1880
1870
0.9678
1.7678
2.5678
3.3678
4.1678
4.9678
5.7678
6.5678
7.3678
8.1678
8.9678
9.7678
10.5678
11.3678
12.1678
12.9678
13.7678
14.5678
15.3678
16.1678
16.9678
17.7678
18.5678
19.3678
20.1678
20.9678
21.7678
22.5678
23.3678
24.1678
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

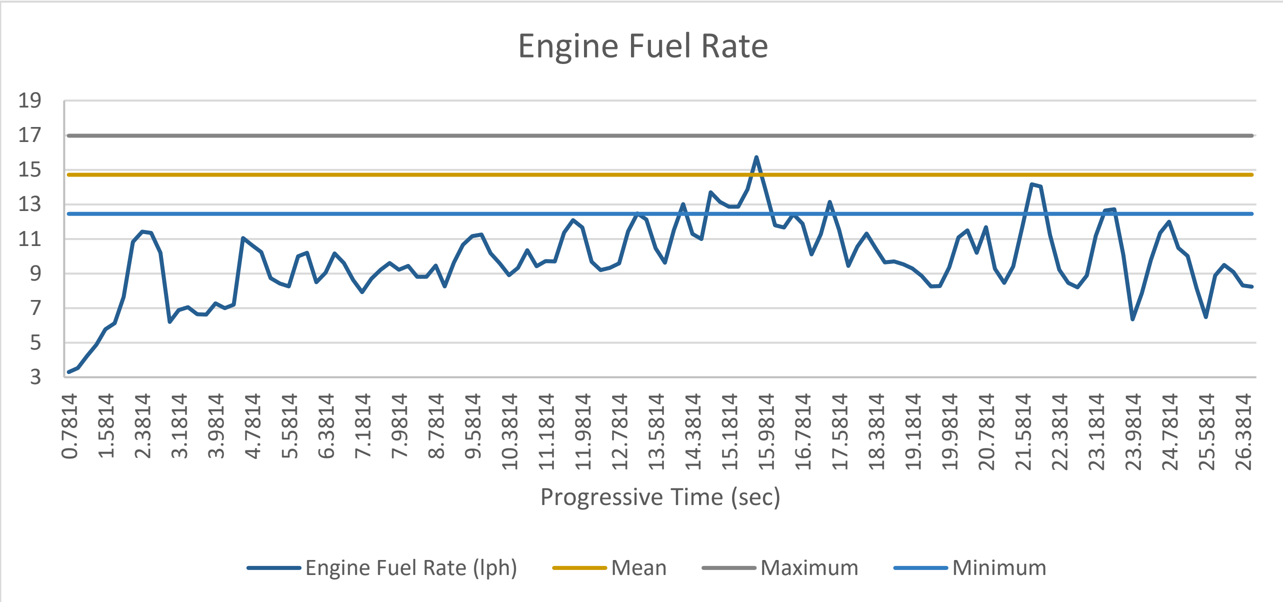
Appendix L – 3PL Deep Ripper – Traveling through washouts data

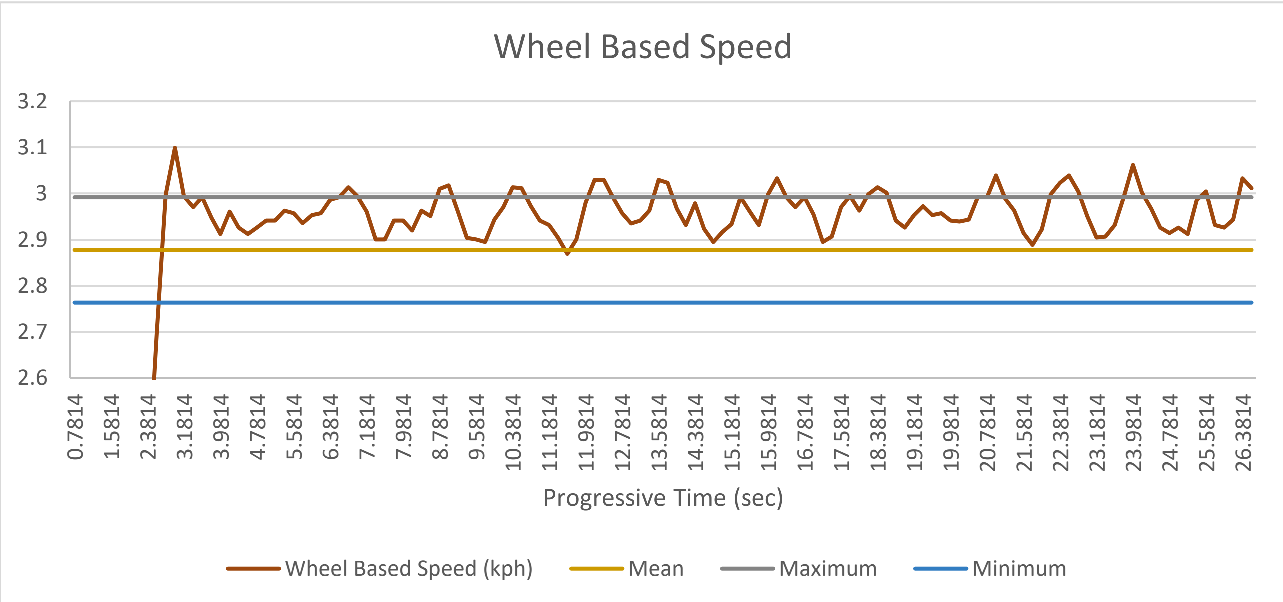
350mm – 3kph

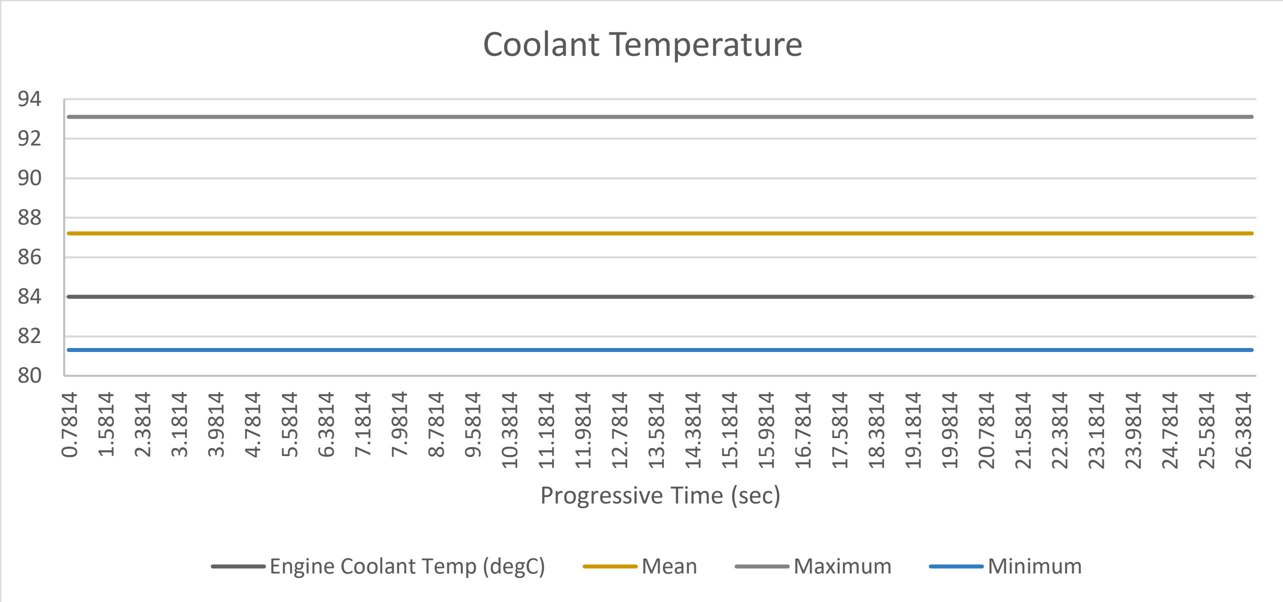




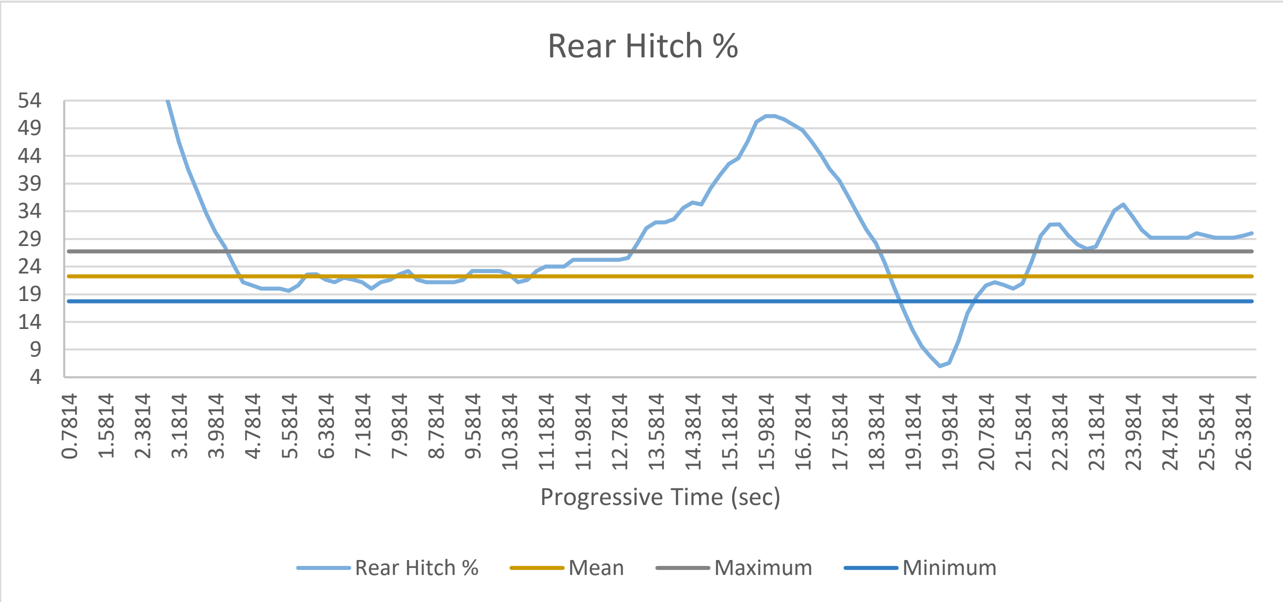

Speed
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

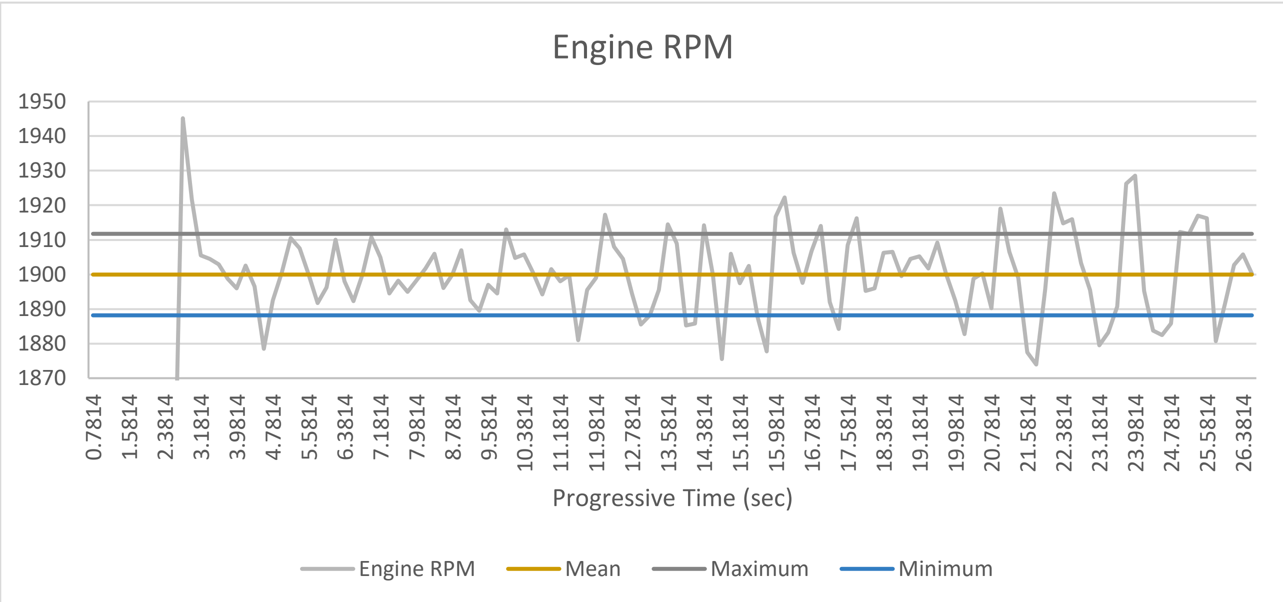

Wheel Based Speed
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum



Coolant Temperature
94
92
90
88
86
84
82
80
0.7814
1.5814
2.3814
3.1814
3.9814
4.7814
5.5814
6.3814
7.1814
7.9814
8.7814
9.5814
10.3814
11.1814
11.9814
12.7814
13.5814
14.3814
15.1814
15.9814
16.7814
17.5814
18.3814
19.1814
19.9814
20.7814
21.5814
22.3814
23.1814
23.9814
24.7814
25.5814
26.3814
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

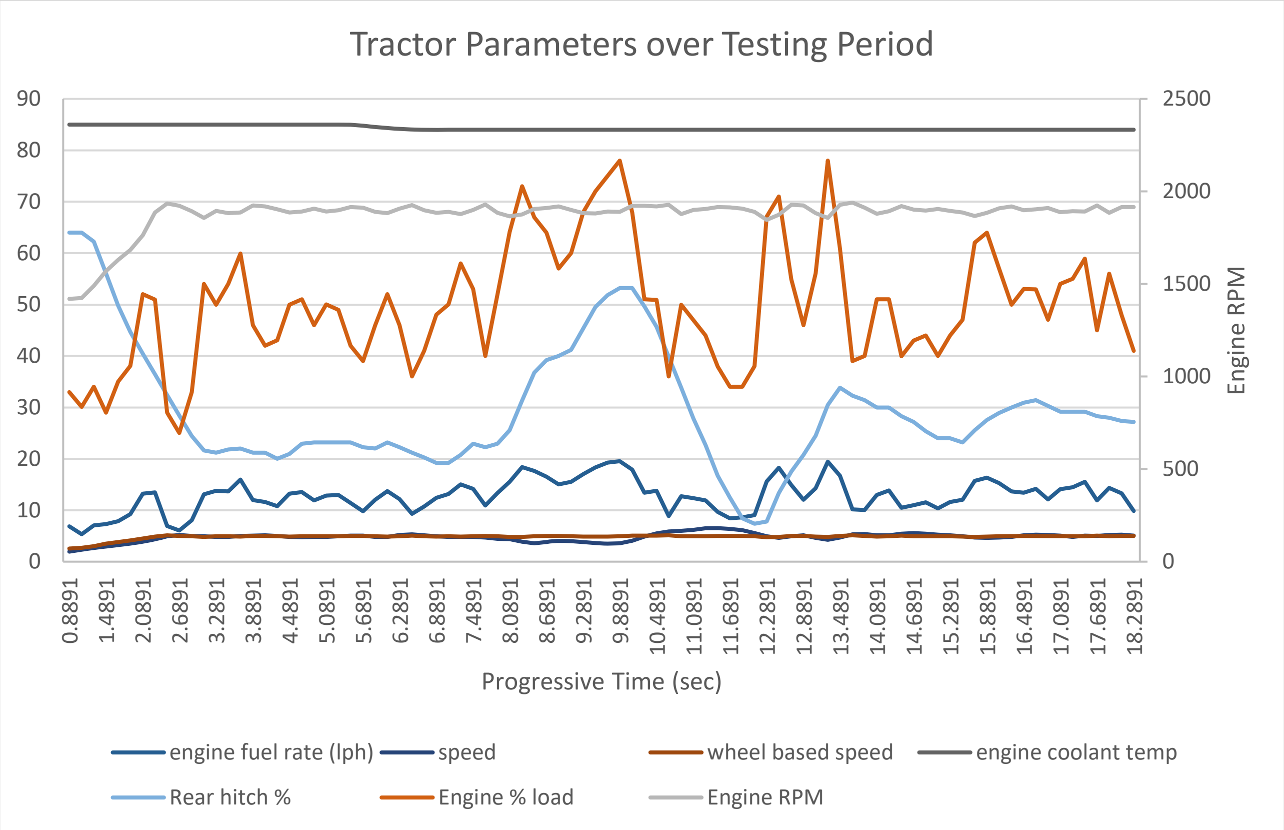


Rear Hitch %
54
49
44
39
34
29
24
19
14
9
4
0.7814
1.5814
2.3814
3.1814
3.9814
4.7814
5.5814
6.3814
7.1814
7.9814
8.7814
9.5814
10.3814
11.1814
11.9814
12.7814
13.5814
14.3814
15.1814
15.9814
16.7814
17.5814
18.3814
19.1814
19.9814
20.7814
21.5814
22.3814
23.1814
23.9814
24.7814
25.5814
26.3814
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

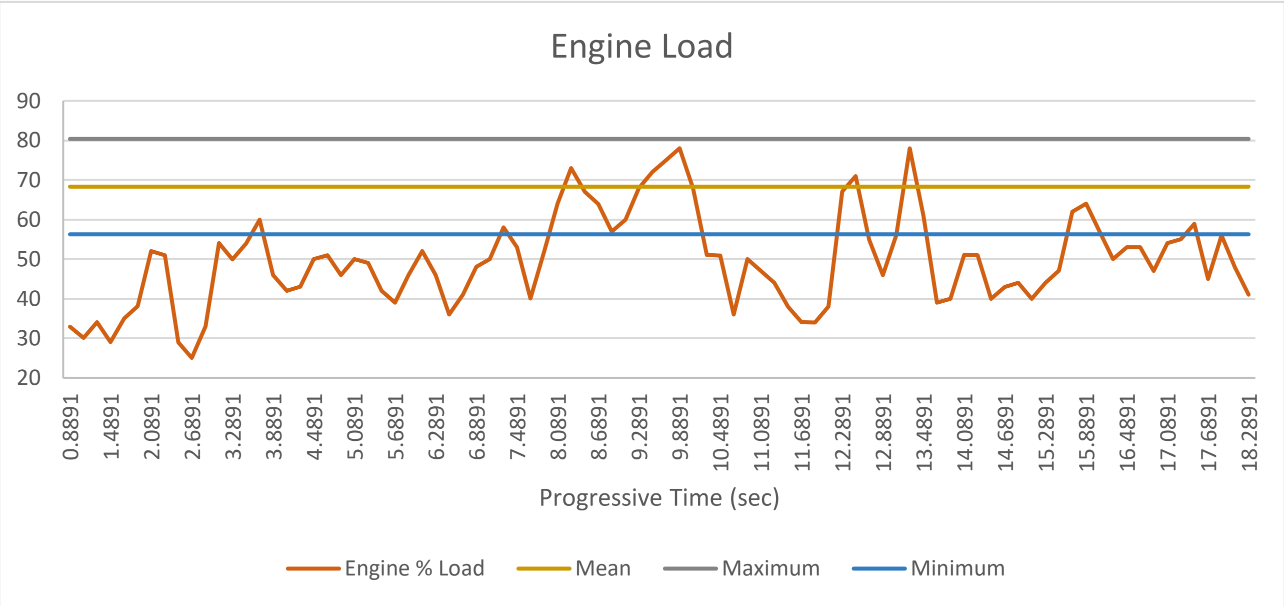


Engine RPM
1950
1940
1930
1920
1910
1900
1890
1880
1870
0.7814
1.5814
2.3814
3.1814
3.9814
4.7814
5.5814
6.3814
7.1814
7.9814
8.7814
9.5814
10.3814
11.1814
11.9814
12.7814
13.5814
14.3814
15.1814
15.9814
16.7814
17.5814
18.3814
19.1814
19.9814
20.7814
21.5814
22.3814
23.1814
23.9814
24.7814
25.5814
26.3814
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

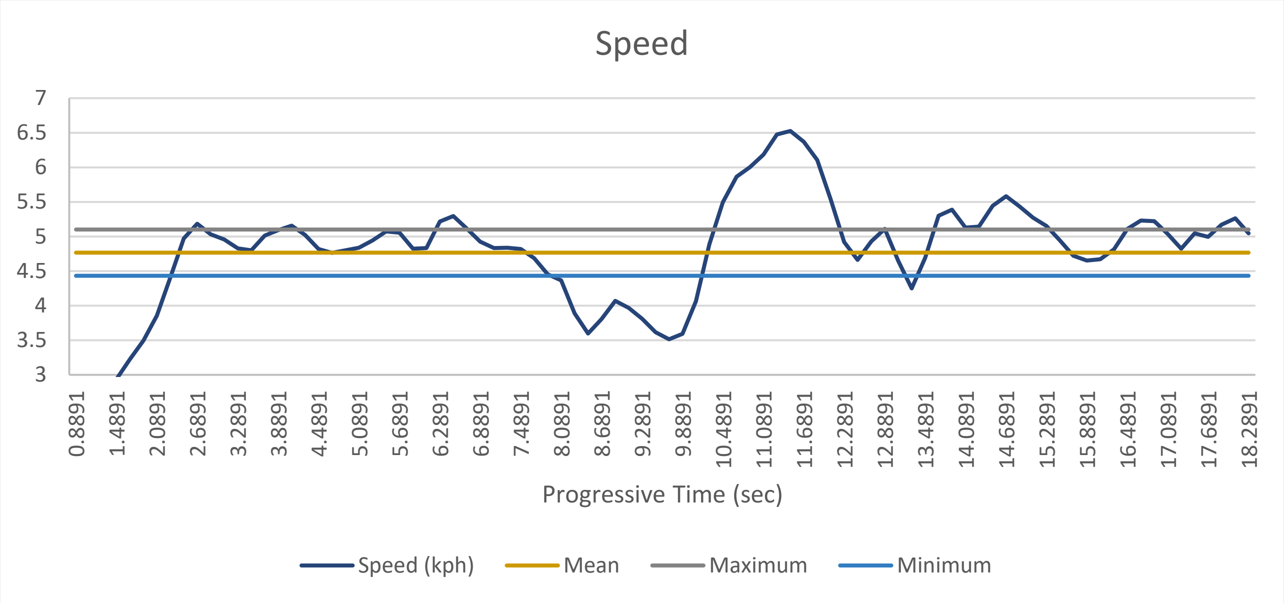
350mm – 5kph

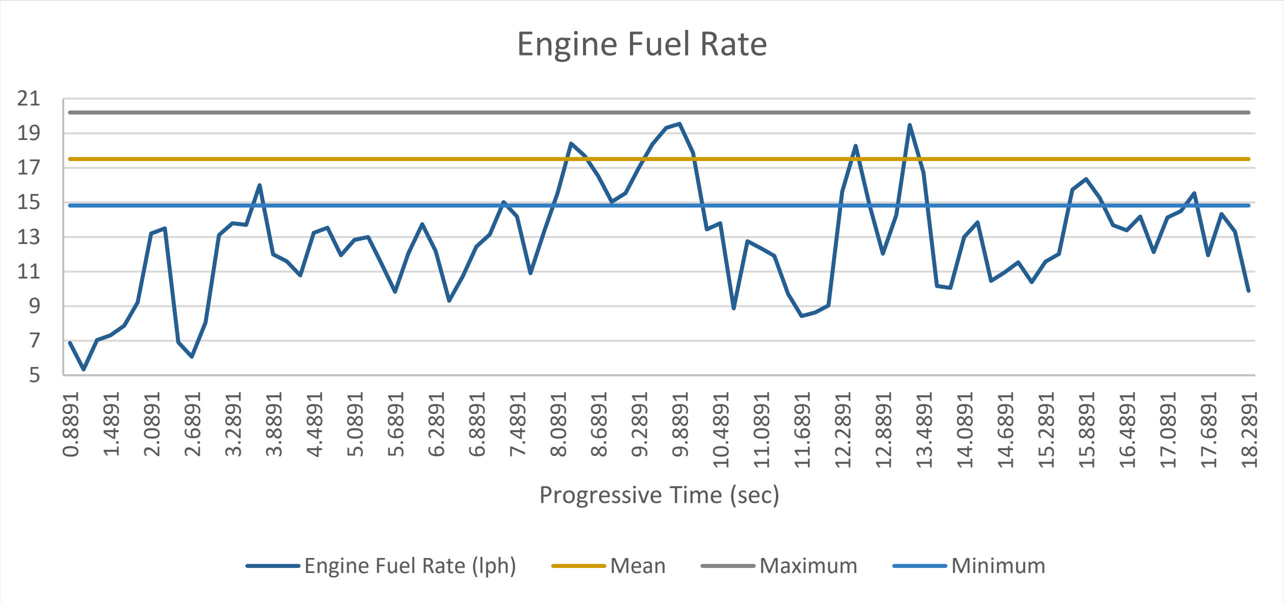


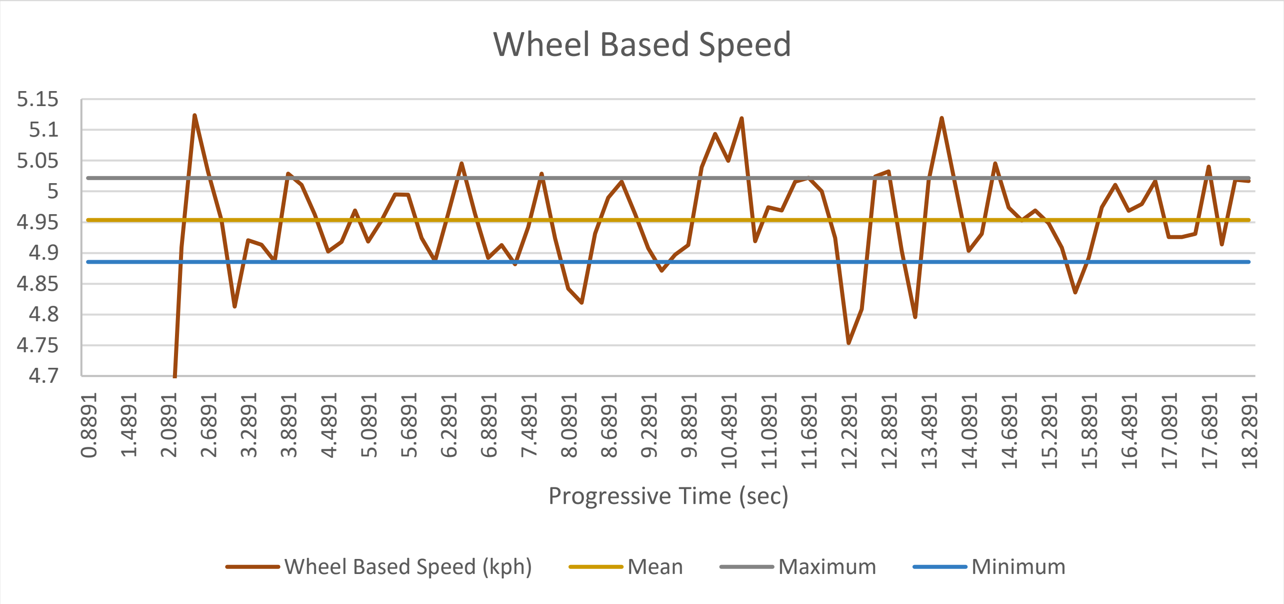
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Engine RPM
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

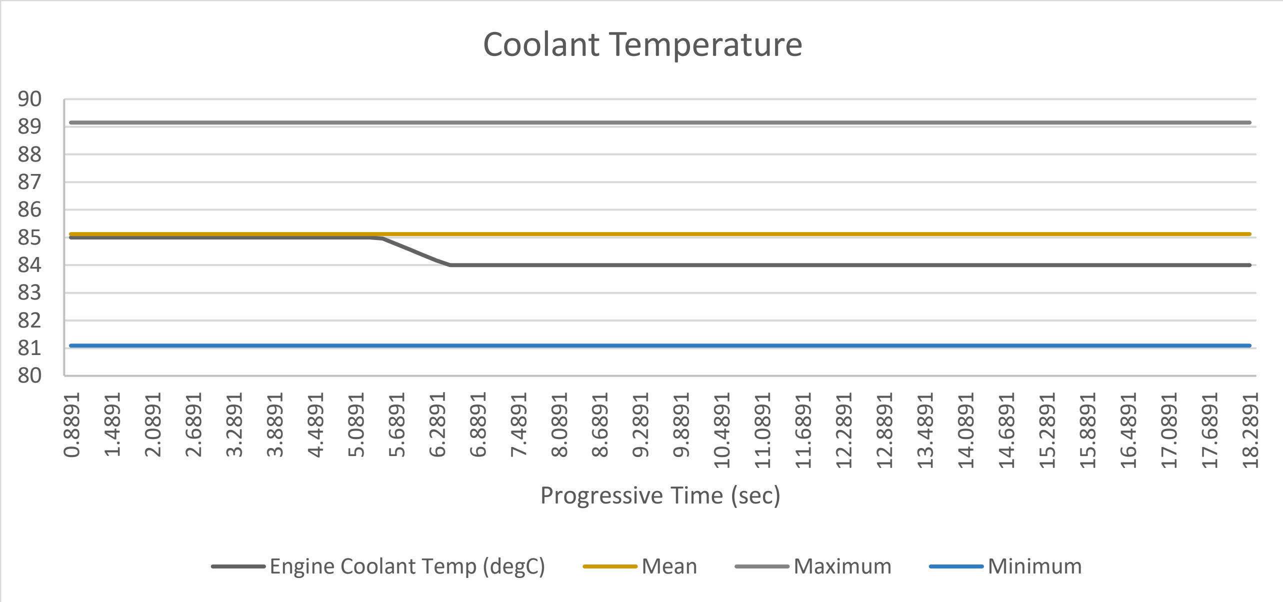


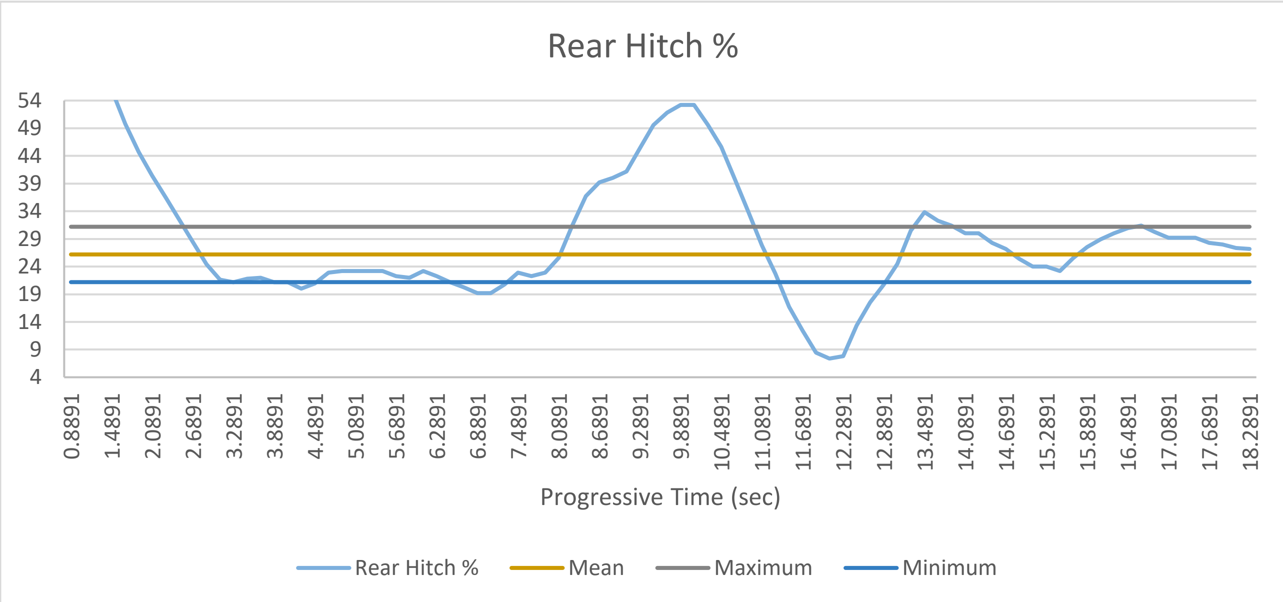
Engine Load
90
80
70
60
50
40
30
20
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

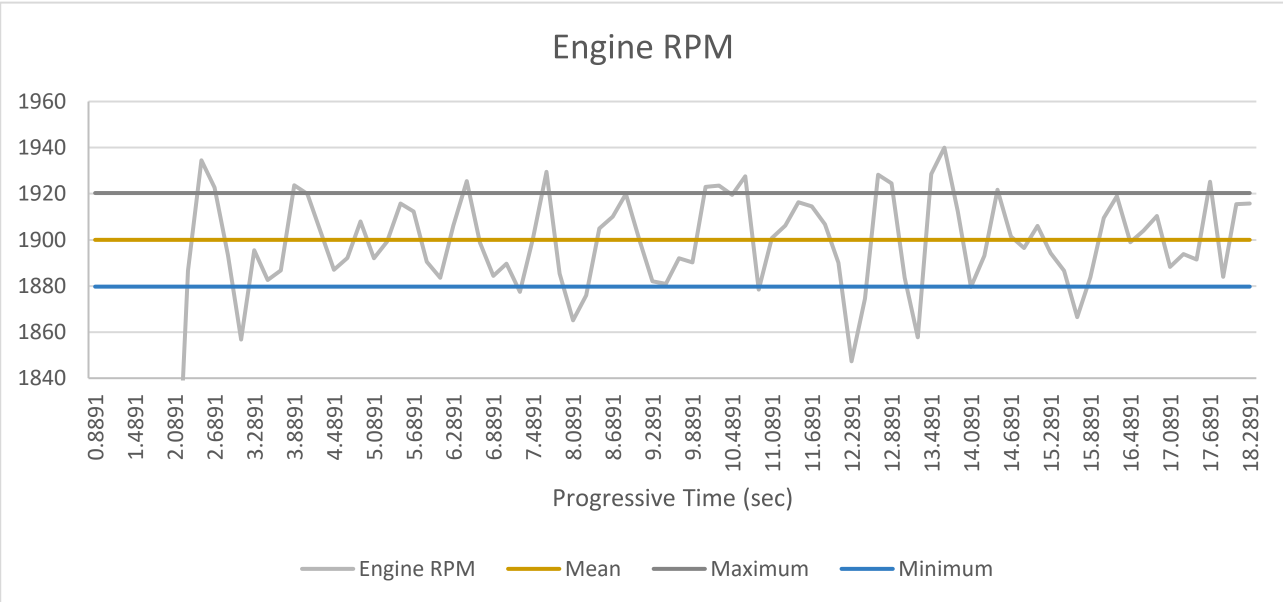

Speed
7
6.5
6
5.5
5
4.5
4
3.5
3
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
21
19
17
15
13
11
9
7
5
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

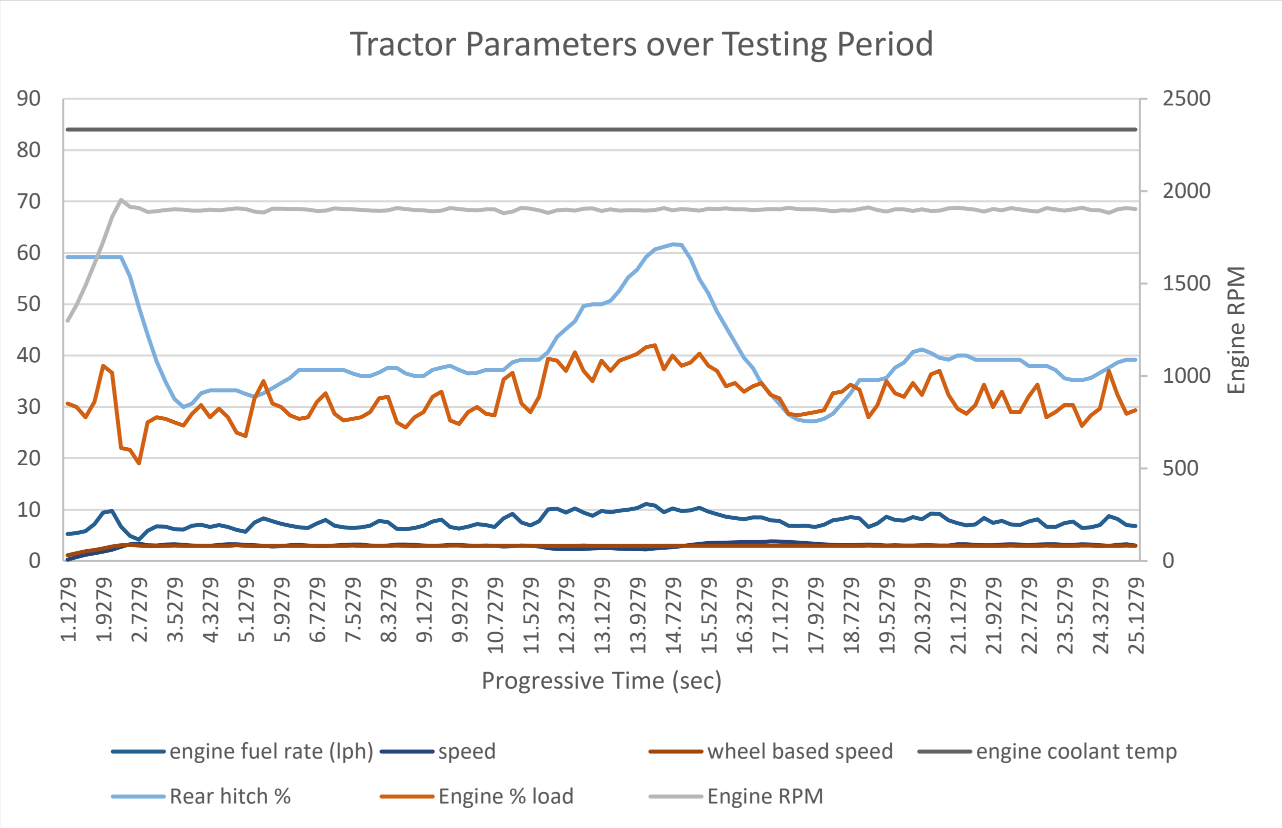

Wheel Based Speed
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
4.75
4.7
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
90
89
88
87
86
85
84
83
82
81
80
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

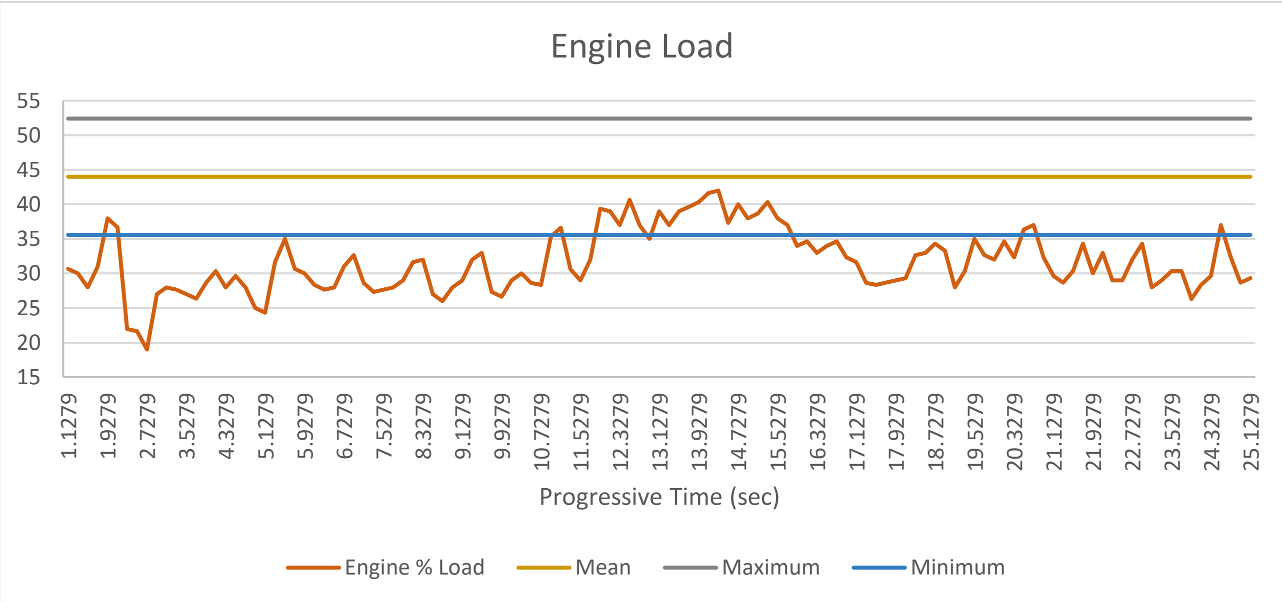

Rear Hitch %
54
49
44
39
34
29
24
19
14
9
4
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1960
1940
1920
1900
1880
1860
1840
0.8891
1.4891
2.0891
2.6891
3.2891
3.8891
4.4891
5.0891
5.6891
6.2891
6.8891
7.4891
8.0891
8.6891
9.2891
9.8891
10.4891
11.0891
11.6891
12.2891
12.8891
13.4891
14.0891
14.6891
15.2891
15.8891
16.4891
17.0891
17.6891
18.2891
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

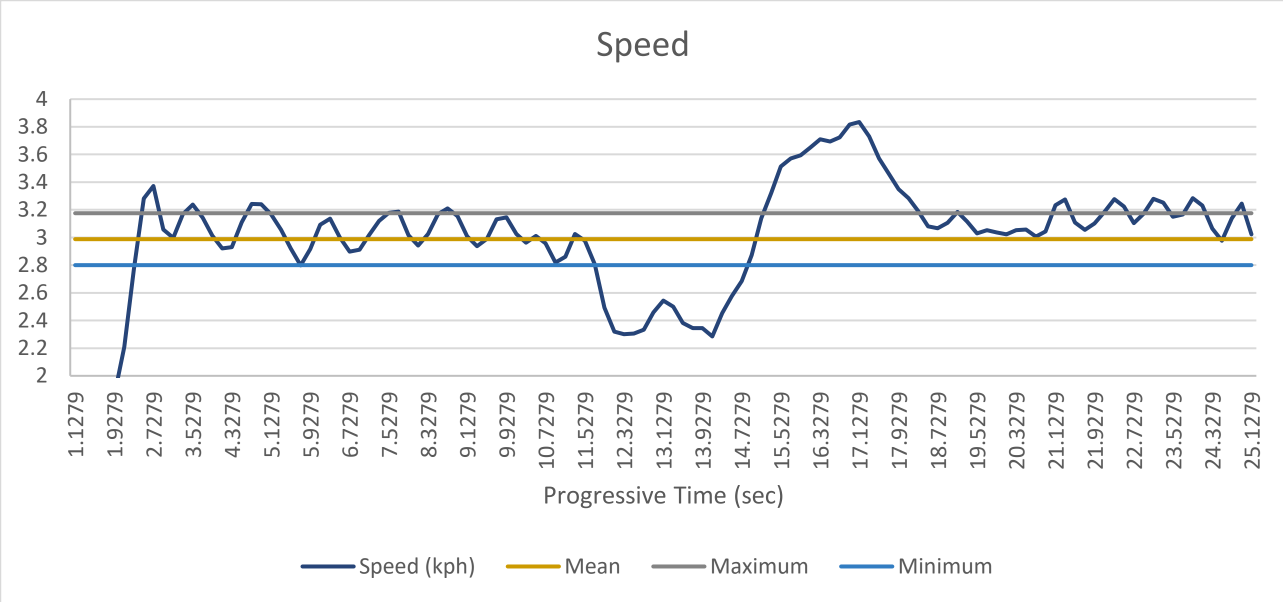
300mm – 3kph

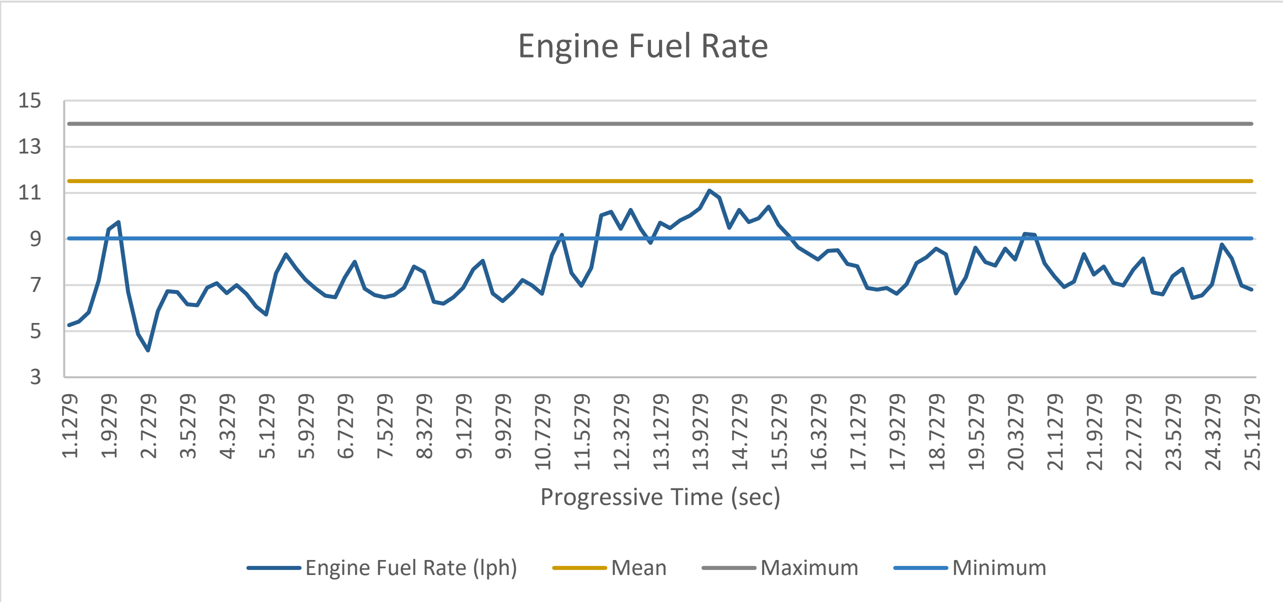


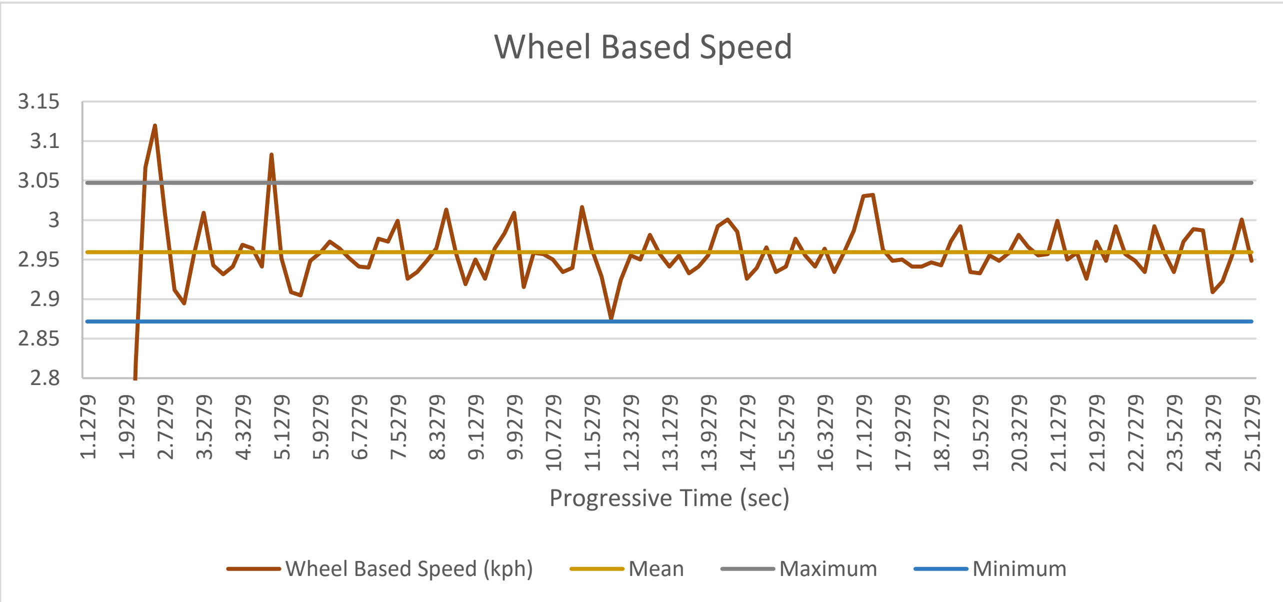
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Engine RPM
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

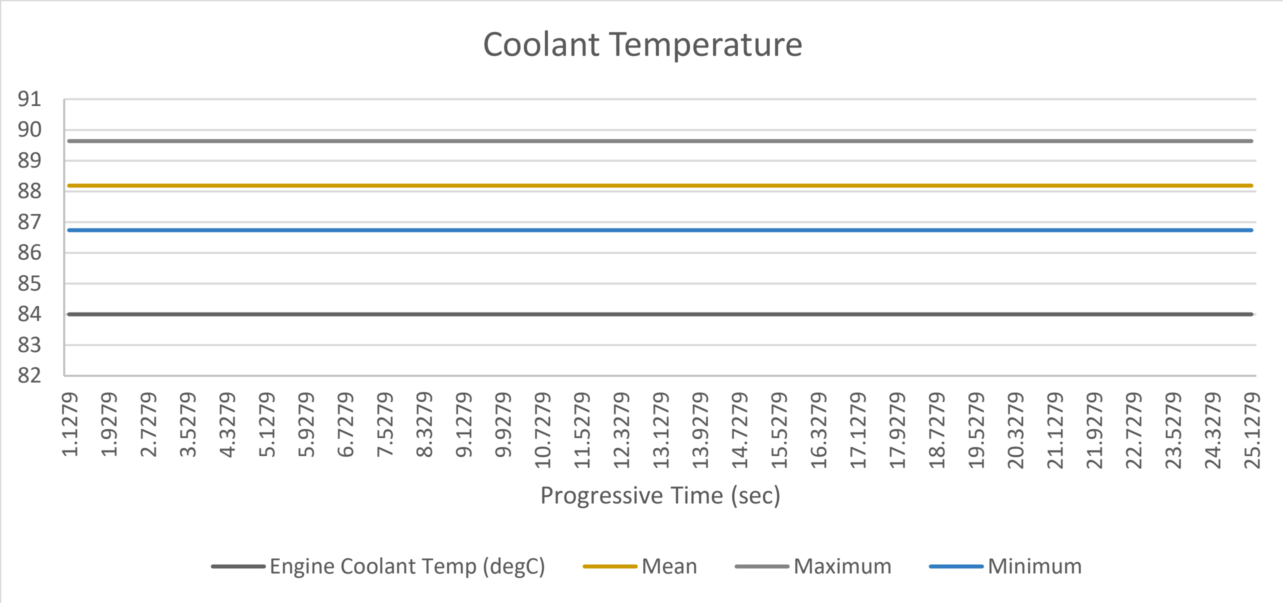


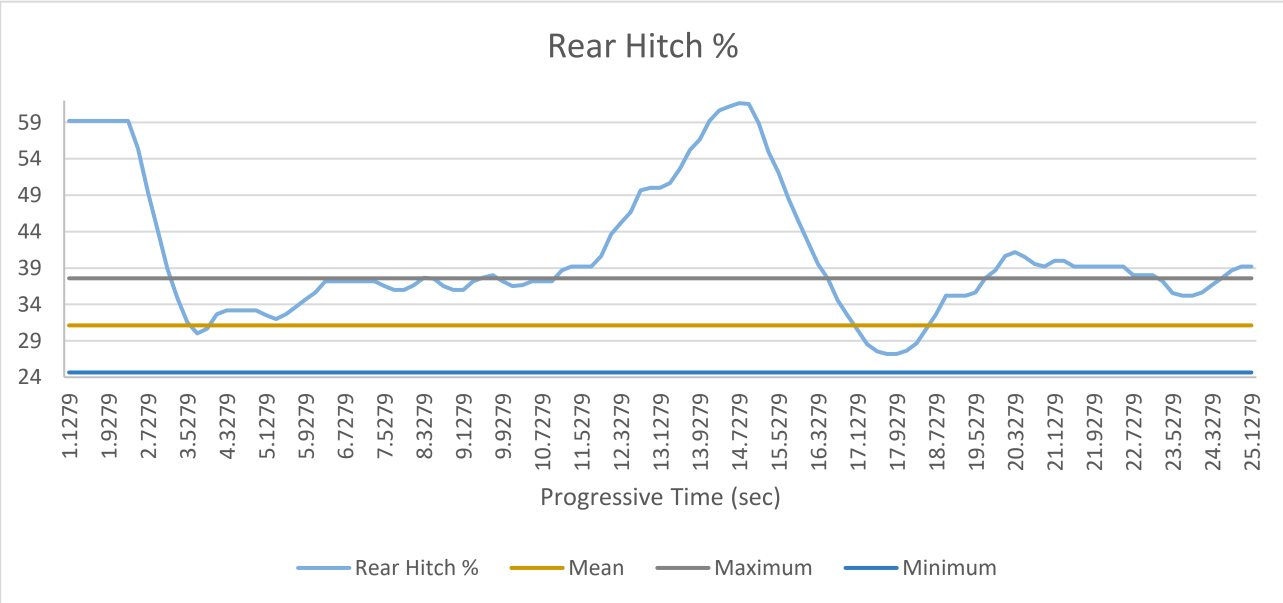
Engine Load
55
50
45
40
35
30
25
20
15
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

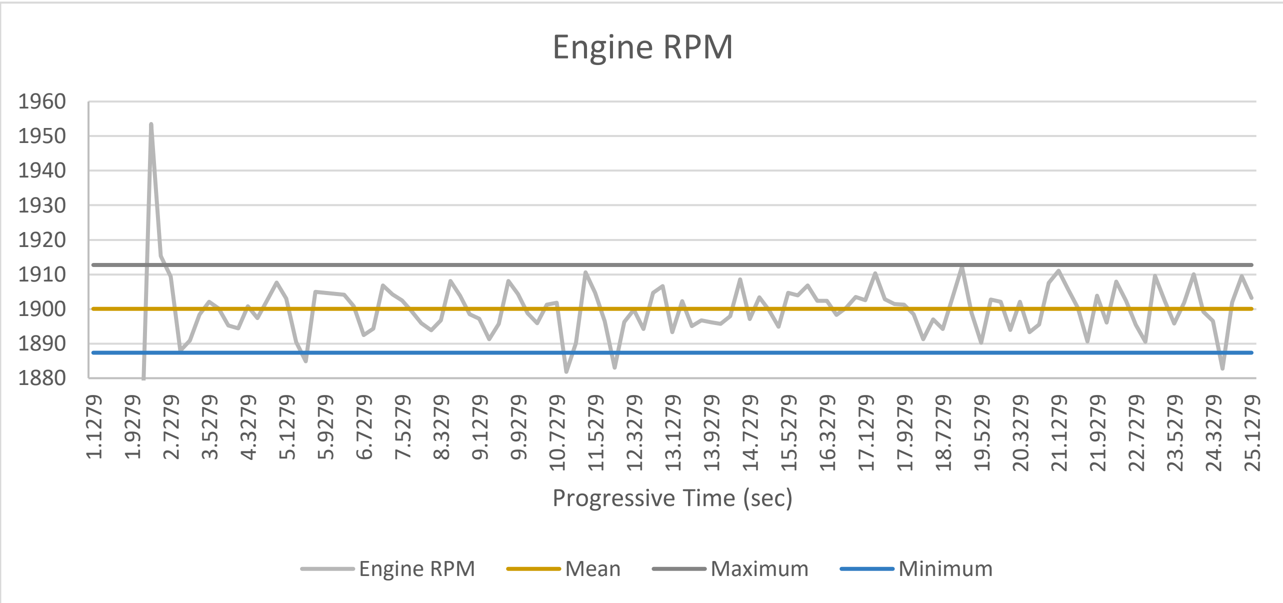

Speed
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
15
13
11
9
7
5
3
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

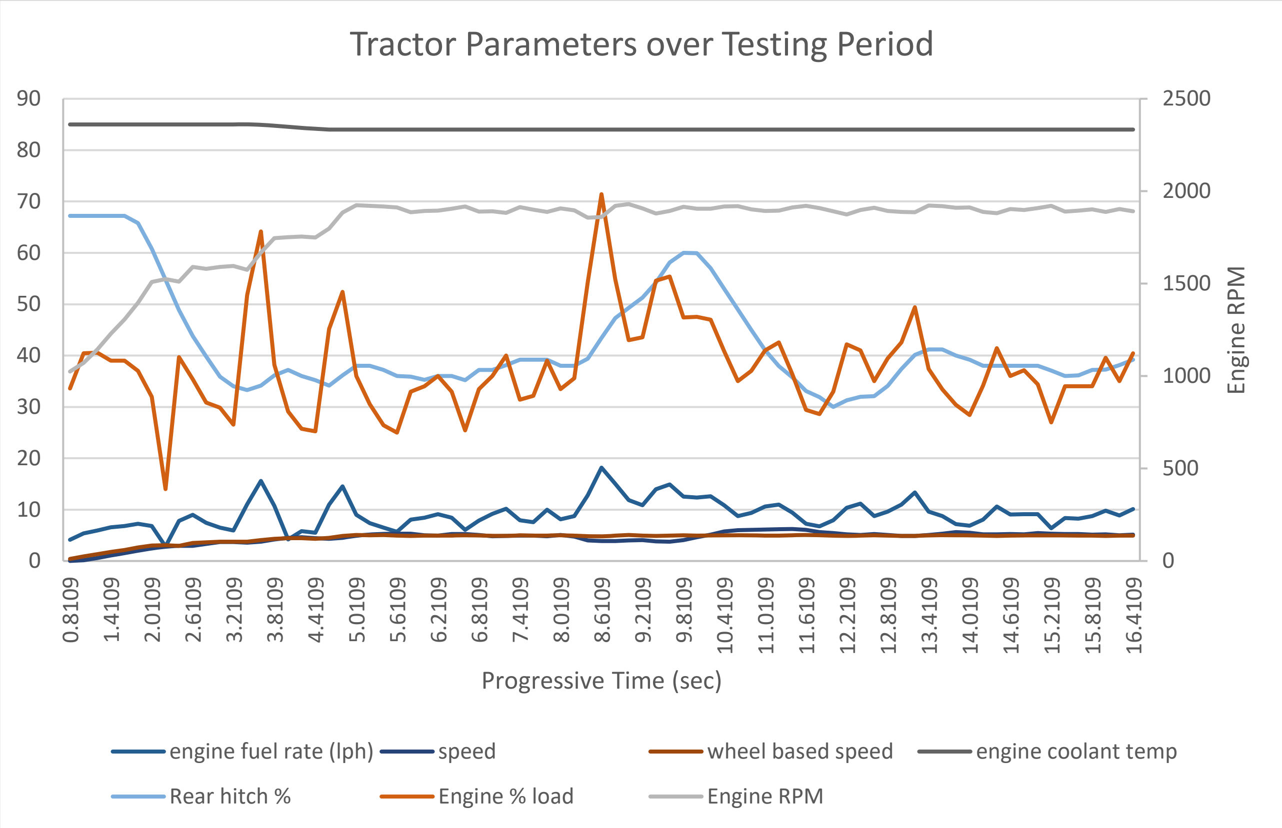

Wheel Based Speed
3.15
3.1
3.05
3
2.95
2.9
2.85
2.8
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum


Coolant Temperature
91
90
89
88
87
86
85
84
83
82
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

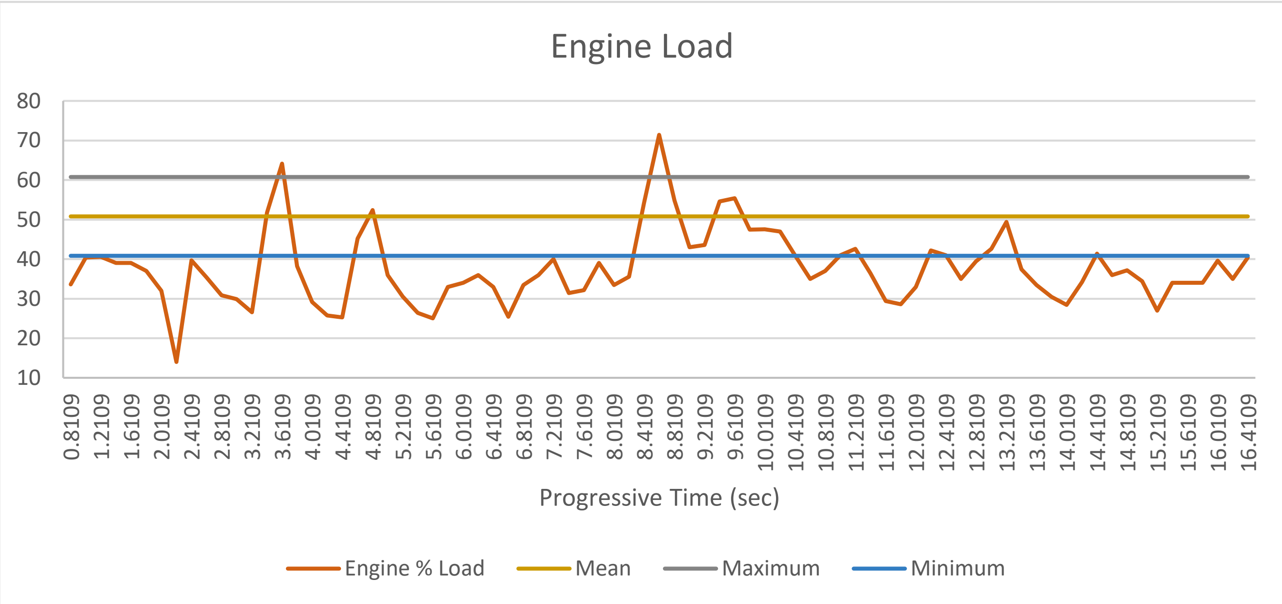

Rear Hitch %
59
54
49
44
39
34
29
24
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum


Engine RPM
1960
1950
1940
1930
1920
1910
1900
1890
1880
1.1279
1.9279
2.7279
3.5279
4.3279
5.1279
5.9279
6.7279
7.5279
8.3279
9.1279
9.9279
10.7279
11.5279
12.3279
13.1279
13.9279
14.7279
15.5279
16.3279
17.1279
17.9279
18.7279
19.5279
20.3279
21.1279
21.9279
22.7279
23.5279
24.3279
25.1279
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

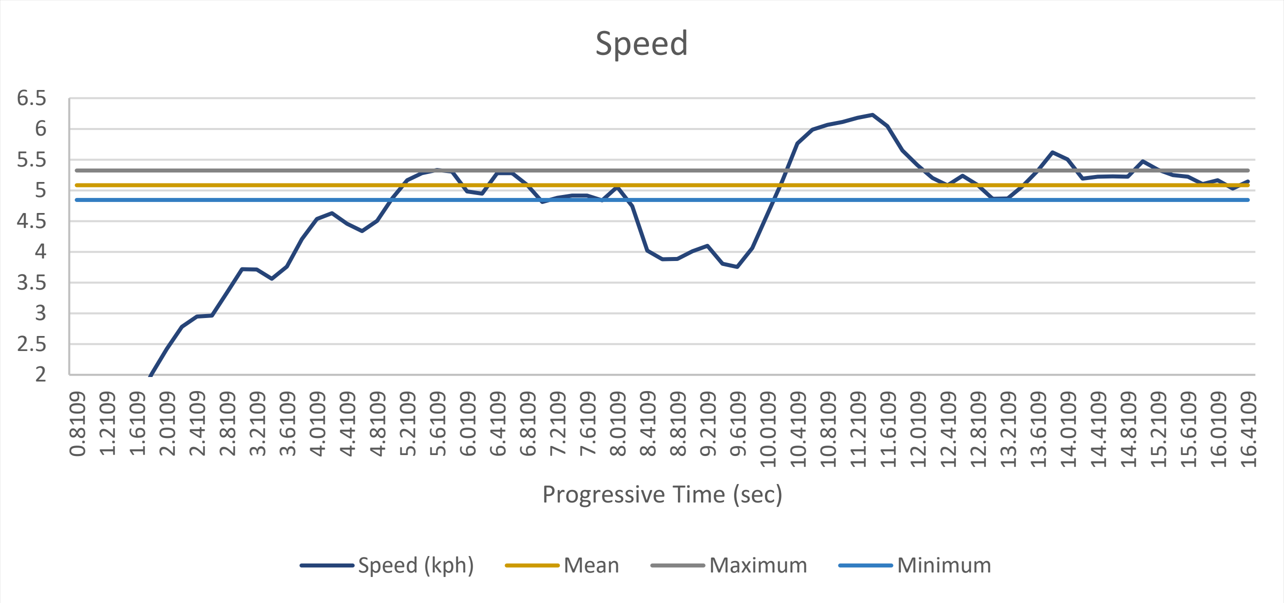
300mm – 5kph

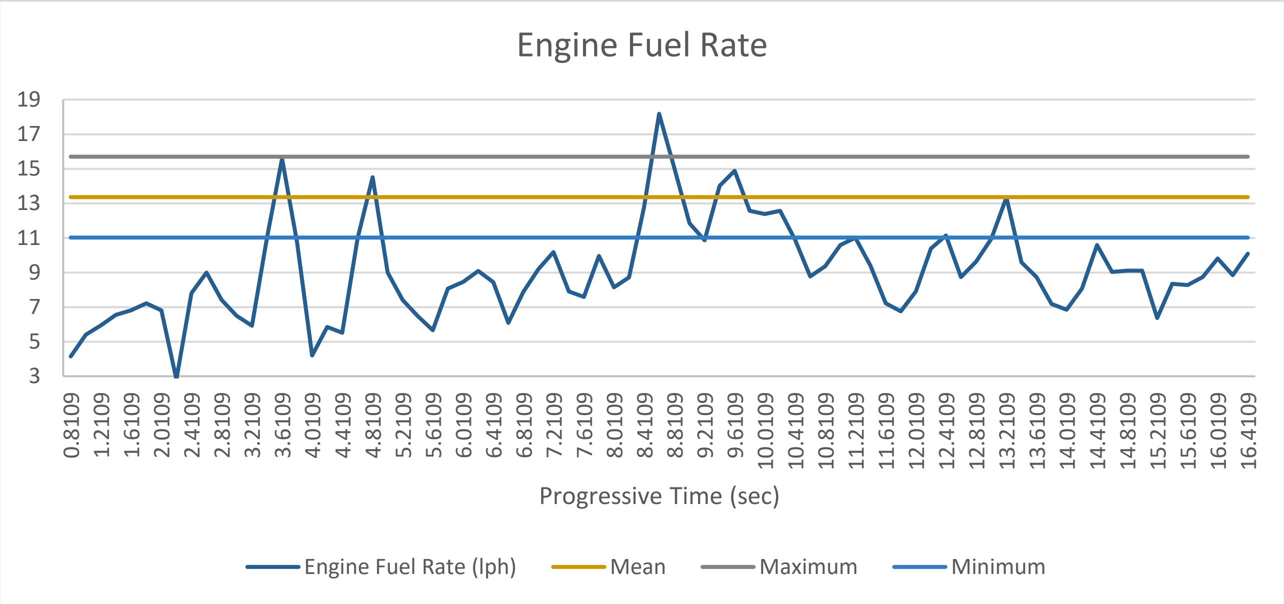


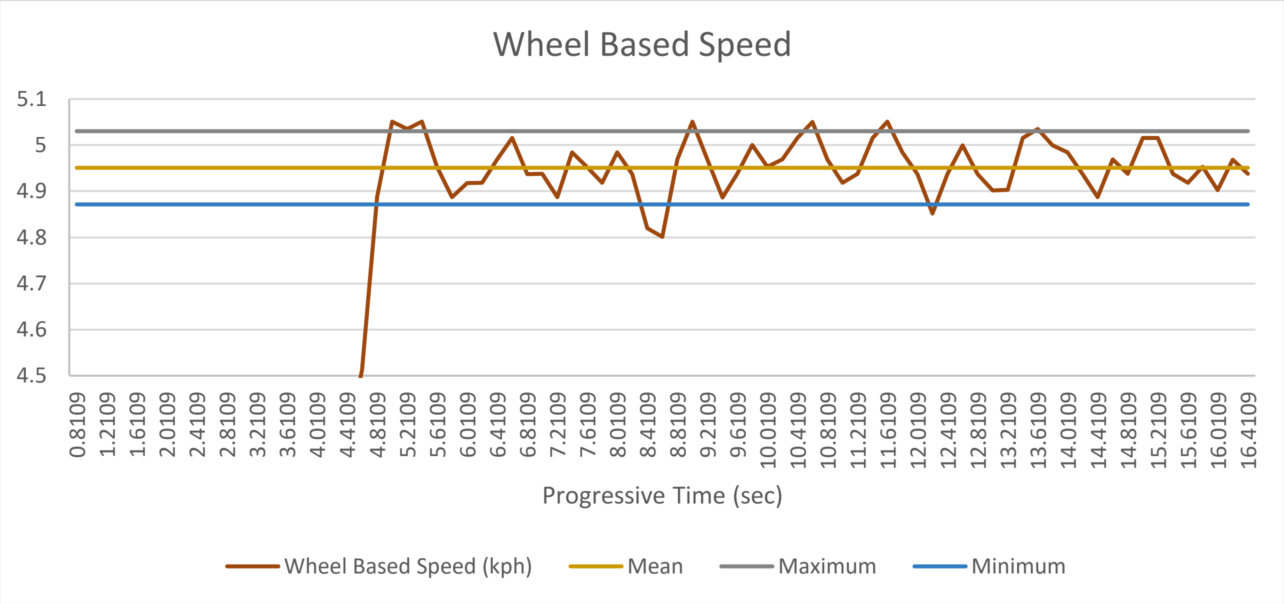
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Engine RPM
0.8109
1.4109
2.0109
2.6109
3.2109
3.8109
4.4109
5.0109
5.6109
6.2109
6.8109
7.4109
8.0109
8.6109
9.2109
9.8109
10.4109
11.0109
11.6109
12.2109
12.8109
13.4109
14.0109
14.6109
15.2109
15.8109
16.4109
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

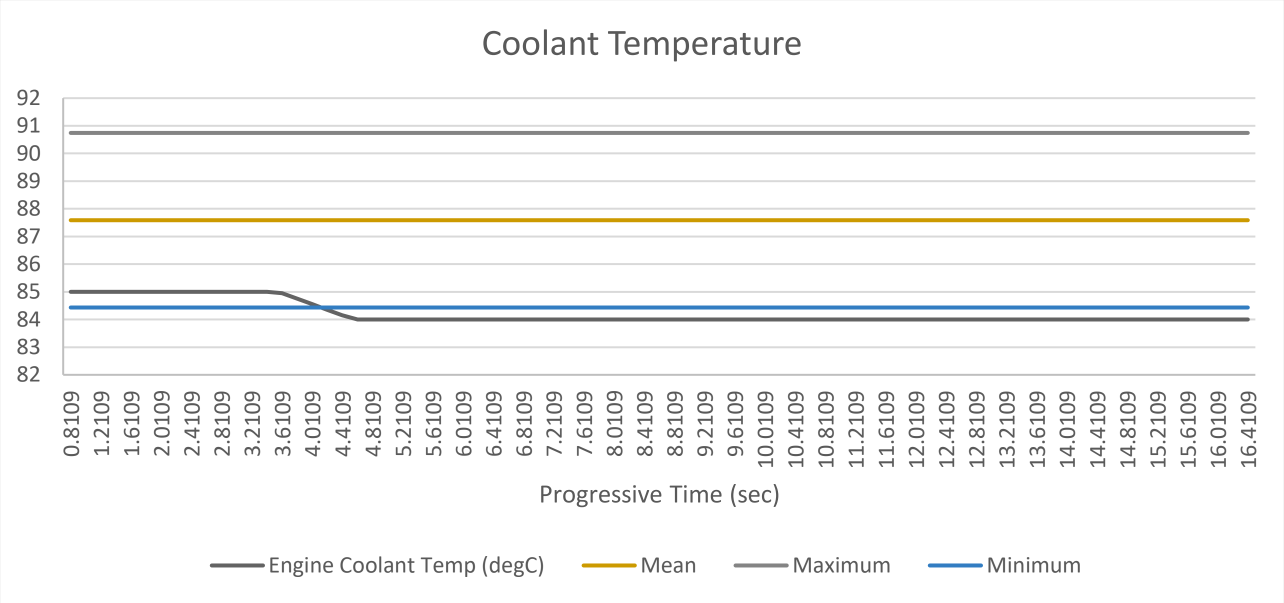


Engine Load
80
70
60
50
40
30
20
10
0.8109
1.2109
1.6109
2.0109
2.4109
2.8109
3.2109
3.6109
4.0109
4.4109
4.8109
5.2109
5.6109
6.0109
6.4109
6.8109
7.2109
7.6109
8.0109
8.4109
8.8109
9.2109
9.6109
10.0109
10.4109
10.8109
11.2109
11.6109
12.0109
12.4109
12.8109
13.2109
13.6109
14.0109
14.4109
14.8109
15.2109
15.6109
16.0109
16.4109
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

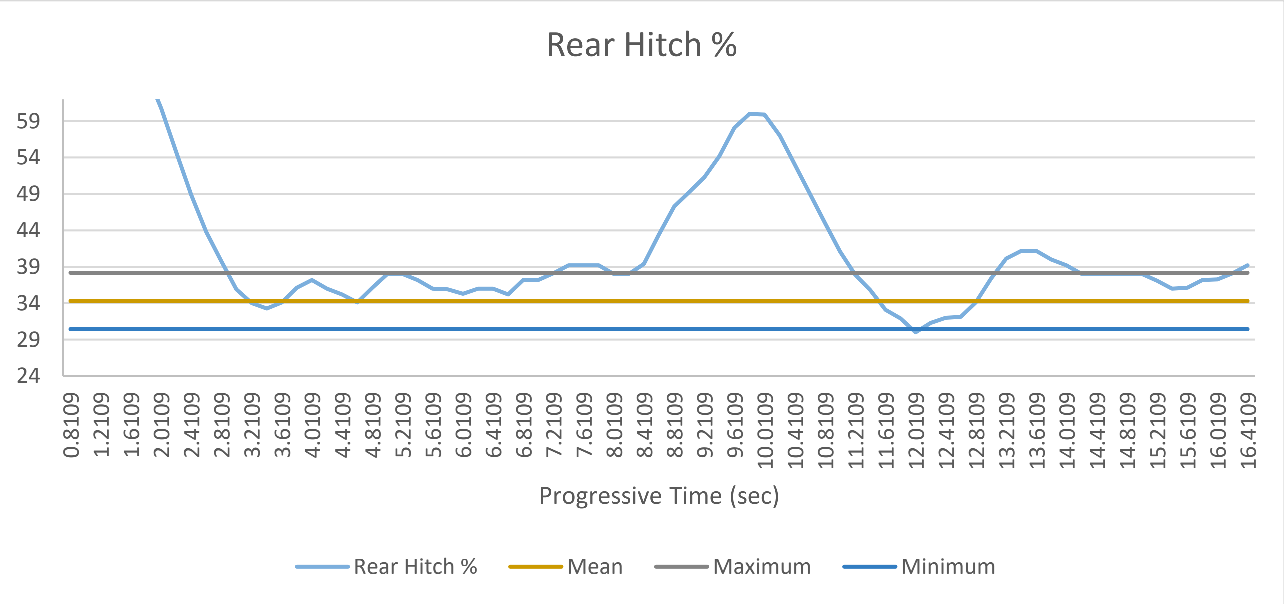

Speed
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
0.8109 1.2109 1.6109 2.0109 2.4109 2.8109 3.2109 3.6109 4.0109 4.4109 4.8109 5.2109 5.6109 6.0109 6.4109 6.8109 7.2109 7.6109 8.0109 8.4109 8.8109 9.2109 9.6109 10.0109 10.4109 10.8109 11.2109 11.6109 12.0109 12.4109 12.8109 13.2109 13.6109 14.0109 14.4109 14.8109 15.2109 15.6109 16.0109 16.4109
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
19
17
15
13
11
9
7
5
3
0.8109 1.2109 1.6109 2.0109 2.4109 2.8109 3.2109 3.6109 4.0109 4.4109 4.8109 5.2109 5.6109 6.0109 6.4109 6.8109 7.2109 7.6109 8.0109 8.4109 8.8109 9.2109 9.6109 10.0109 10.4109 10.8109 11.2109 11.6109 12.0109 12.4109 12.8109 13.2109 13.6109 14.0109 14.4109 14.8109 15.2109 15.6109 16.0109 16.4109
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

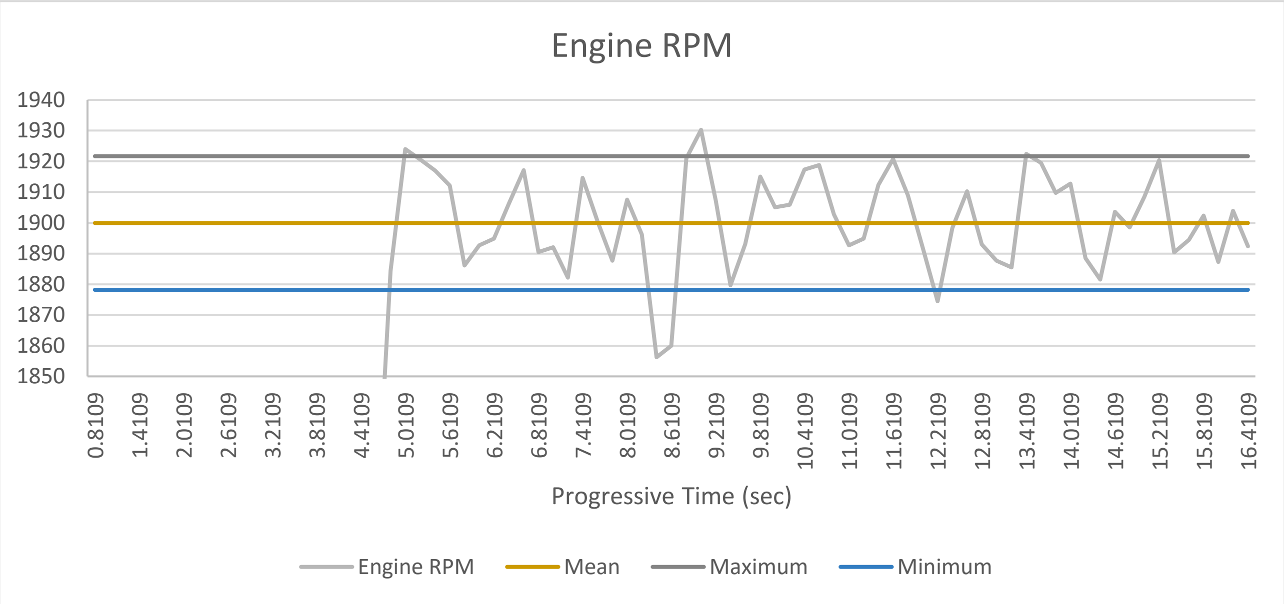

Wheel Based Speed
5.1
5
4.9
4.8
4.7
4.6
4.5
0.8109 1.2109 1.6109 2.0109 2.4109 2.8109 3.2109 3.6109 4.0109 4.4109 4.8109 5.2109 5.6109 6.0109 6.4109 6.8109 7.2109 7.6109 8.0109 8.4109 8.8109 9.2109 9.6109 10.0109 10.4109 10.8109 11.2109 11.6109 12.0109 12.4109 12.8109 13.2109 13.6109 14.0109 14.4109 14.8109 15.2109 15.6109 16.0109 16.4109
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum



Coolant Temperature
92
91
90
89
88
87
86
85
84
83
82
0.8109
1.2109
1.6109
2.0109
2.4109
2.8109
3.2109
3.6109
4.0109
4.4109
4.8109
5.2109
5.6109
6.0109
6.4109
6.8109
7.2109
7.6109
8.0109
8.4109
8.8109
9.2109
9.6109
10.0109
10.4109
10.8109
11.2109
11.6109
12.0109
12.4109
12.8109
13.2109
13.6109
14.0109
14.4109
14.8109
15.2109
15.6109
16.0109
16.4109
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

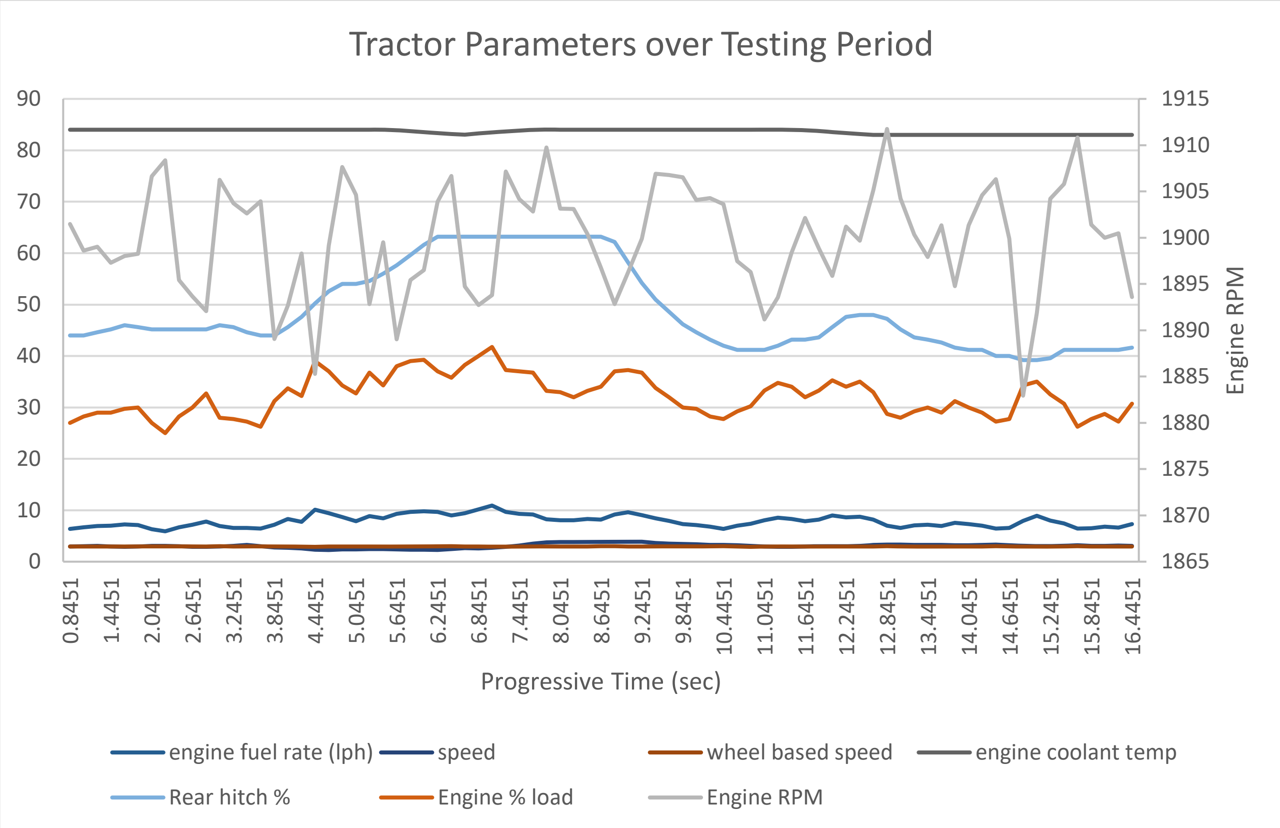


Rear Hitch %
59
54
49
44
39
34
29
24
0.8109
1.2109
1.6109
2.0109
2.4109
2.8109
3.2109
3.6109
4.0109
4.4109
4.8109
5.2109
5.6109
6.0109
6.4109
6.8109
7.2109
7.6109
8.0109
8.4109
8.8109
9.2109
9.6109
10.0109
10.4109
10.8109
11.2109
11.6109
12.0109
12.4109
12.8109
13.2109
13.6109
14.0109
14.4109
14.8109
15.2109
15.6109
16.0109
16.4109
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

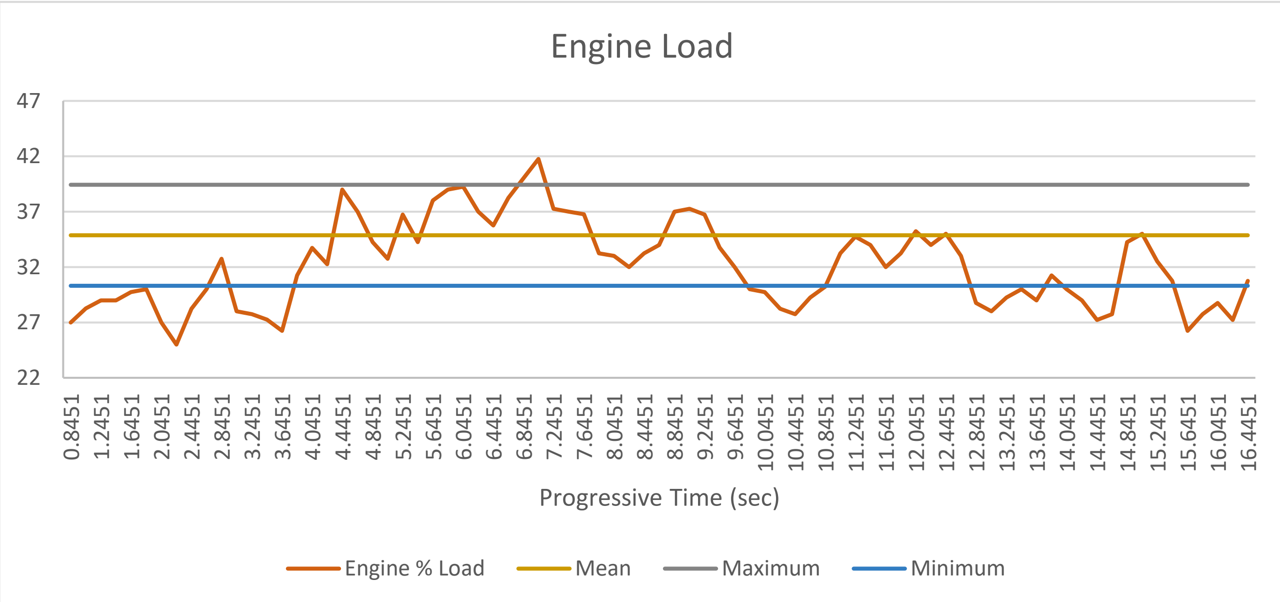


Engine RPM
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
0.8109
1.4109
2.0109
2.6109
3.2109
3.8109
4.4109
5.0109
5.6109
6.2109
6.8109
7.4109
8.0109
8.6109
9.2109
9.8109
10.4109
11.0109
11.6109
12.2109
12.8109
13.4109
14.0109
14.6109
15.2109
15.8109
16.4109
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

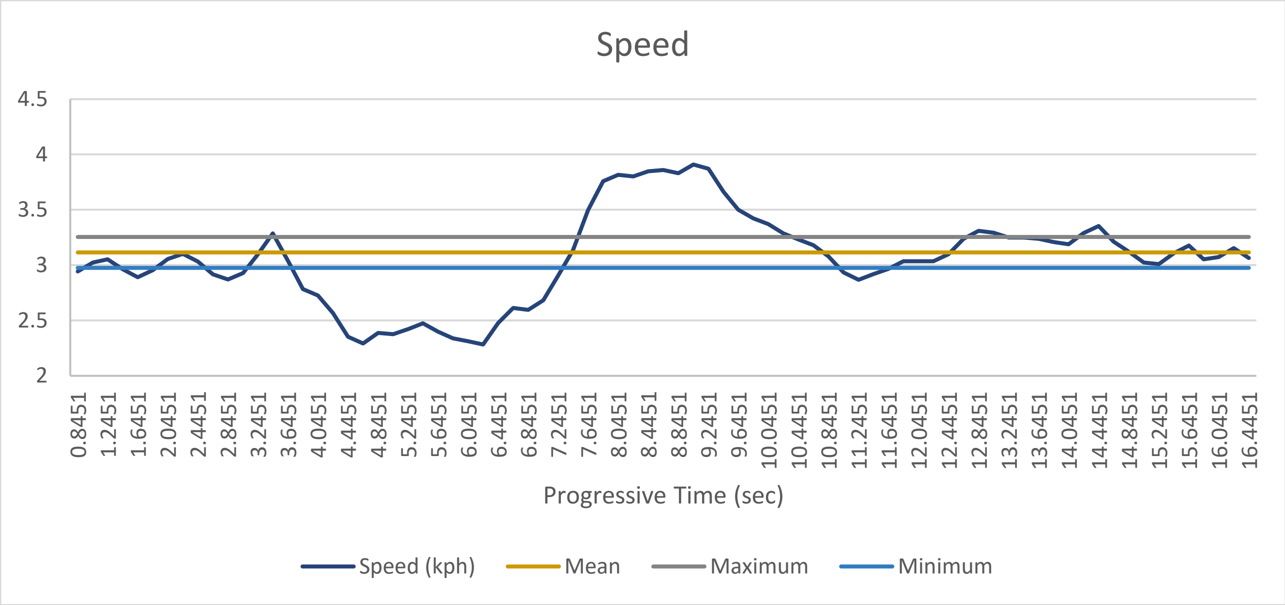
200mm – 3kph

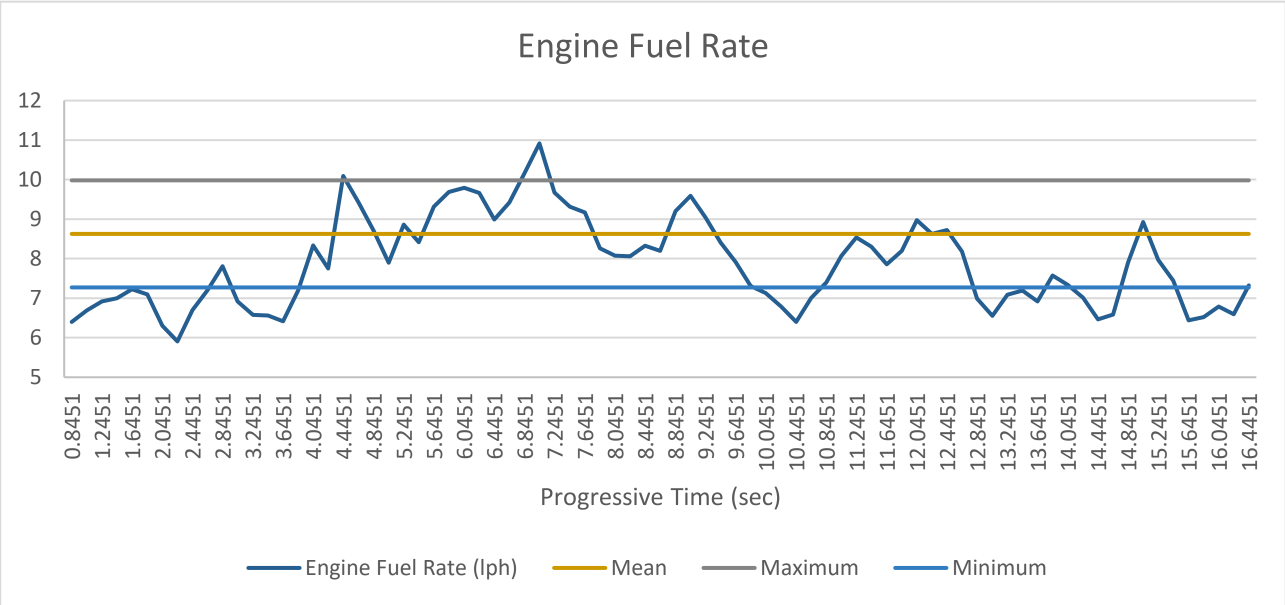


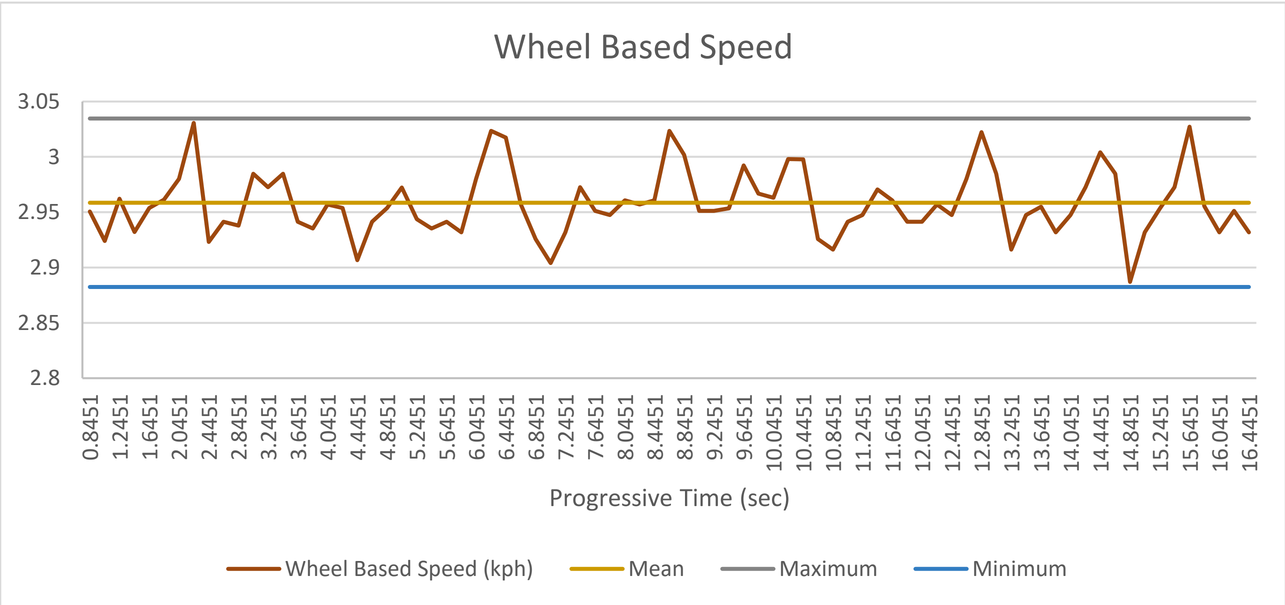
Tractor Parameters over Testing Period
90
80
70
60
50
40
30
20
10
0
1915
1910
1905
1900
1895
1890
1885
1880
1875
1870
1865
Engine RPM
0.8451
1.4451
2.0451
2.6451
3.2451
3.8451
4.4451
5.0451
5.6451
6.2451
6.8451
7.4451
8.0451
8.6451
9.2451
9.8451
10.4451
11.0451
11.6451
12.2451
12.8451
13.4451
14.0451
14.6451
15.2451
15.8451
16.4451
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

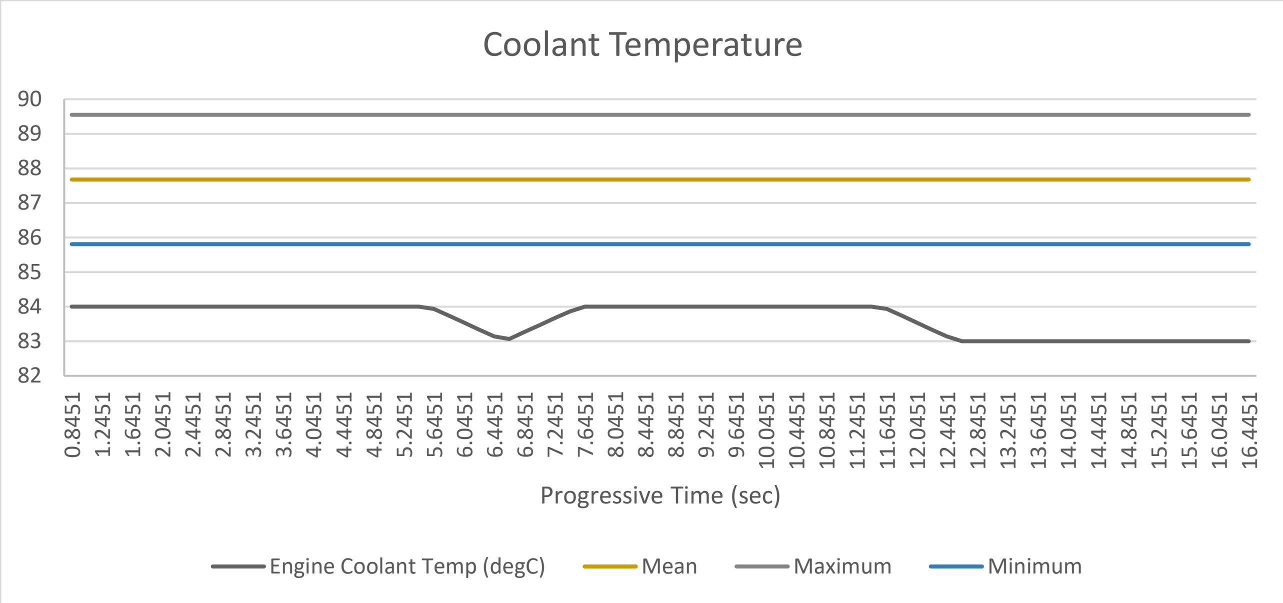


Engine Load
47
42
37
32
27
22
0.8451
1.2451
1.6451
2.0451
2.4451
2.8451
3.2451
3.6451
4.0451
4.4451
4.8451
5.2451
5.6451
6.0451
6.4451
6.8451
7.2451
7.6451
8.0451
8.4451
8.8451
9.2451
9.6451
10.0451
10.4451
10.8451
11.2451
11.6451
12.0451
12.4451
12.8451
13.2451
13.6451
14.0451
14.4451
14.8451
15.2451
15.6451
16.0451
16.4451
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

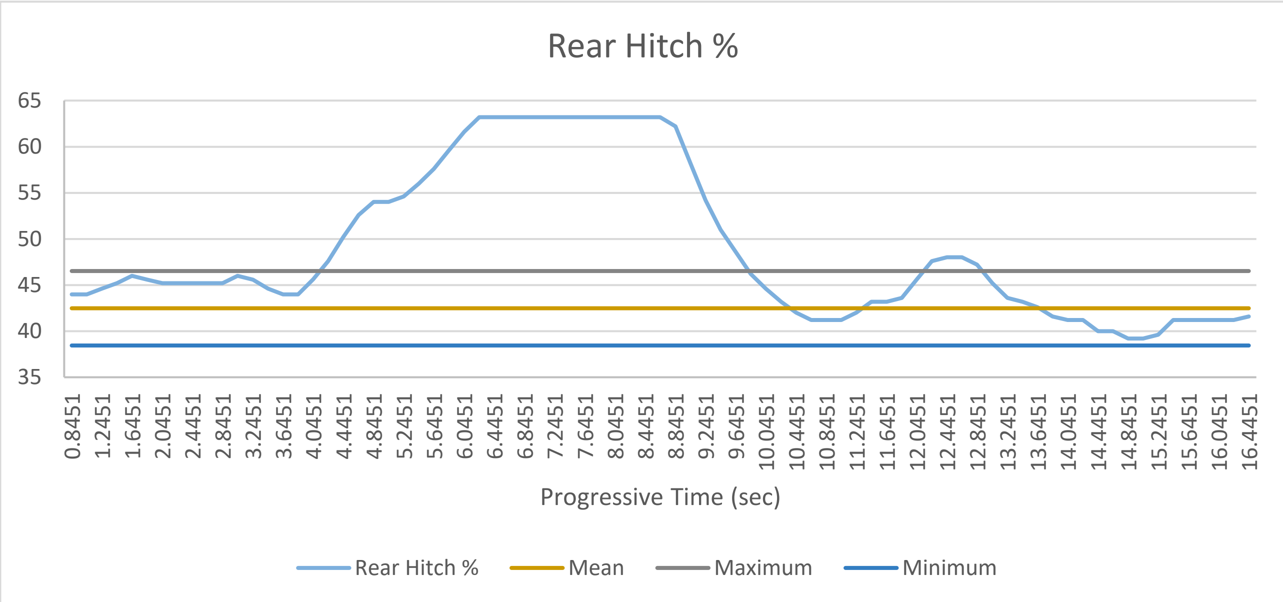

Speed
4.5
4
3.5
3
2.5
2
0.8451 1.2451 1.6451 2.0451 2.4451 2.8451 3.2451 3.6451 4.0451 4.4451 4.8451 5.2451 5.6451 6.0451 6.4451 6.8451 7.2451 7.6451 8.0451 8.4451 8.8451 9.2451 9.6451 10.0451 10.4451 10.8451 11.2451 11.6451 12.0451 12.4451 12.8451 13.2451 13.6451 14.0451 14.4451 14.8451 15.2451 15.6451 16.0451 16.4451
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
12
11
10
9
8
7
6
5
0.8451 1.2451 1.6451 2.0451 2.4451 2.8451 3.2451 3.6451 4.0451 4.4451 4.8451 5.2451 5.6451 6.0451 6.4451 6.8451 7.2451 7.6451 8.0451 8.4451 8.8451 9.2451 9.6451 10.0451 10.4451 10.8451 11.2451 11.6451 12.0451 12.4451 12.8451 13.2451 13.6451 14.0451 14.4451 14.8451 15.2451 15.6451 16.0451 16.4451
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum

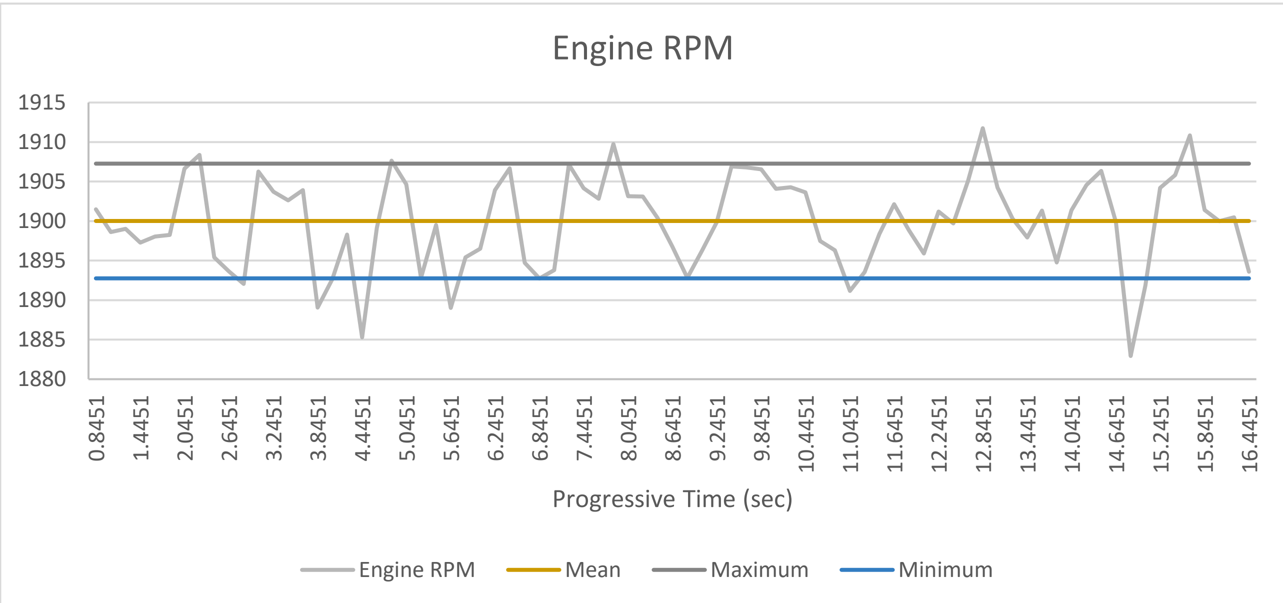

Wheel Based Speed
3.05
3
2.95
2.9
2.85
2.8
0.8451 1.2451 1.6451 2.0451 2.4451 2.8451 3.2451 3.6451 4.0451 4.4451 4.8451 5.2451 5.6451 6.0451 6.4451 6.8451 7.2451 7.6451 8.0451 8.4451 8.8451 9.2451 9.6451 10.0451 10.4451 10.8451 11.2451 11.6451 12.0451 12.4451 12.8451 13.2451 13.6451 14.0451 14.4451 14.8451 15.2451 15.6451 16.0451 16.4451
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum



Coolant Temperature
90
89
88
87
86
85
84
83
82
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum

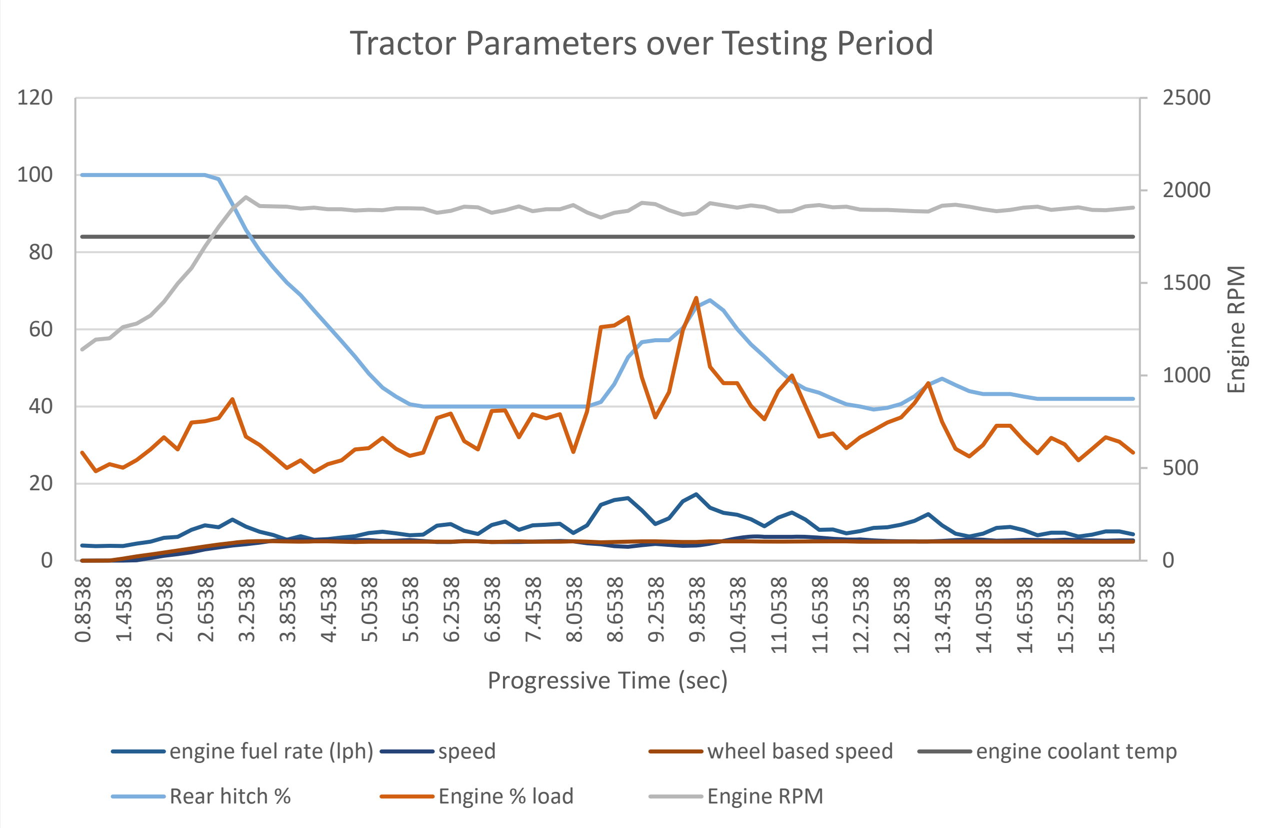


Rear Hitch %
65
60
55
50
45
40
35
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

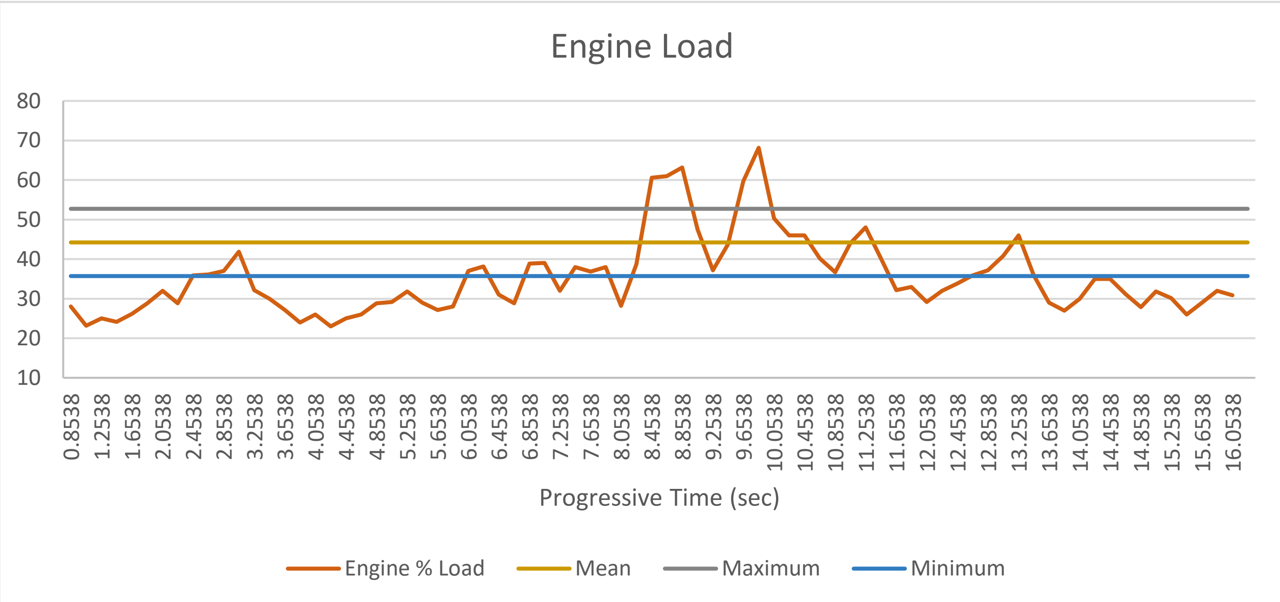


Engine RPM
1915
1910
1905
1900
1895
1890
1885
1880
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

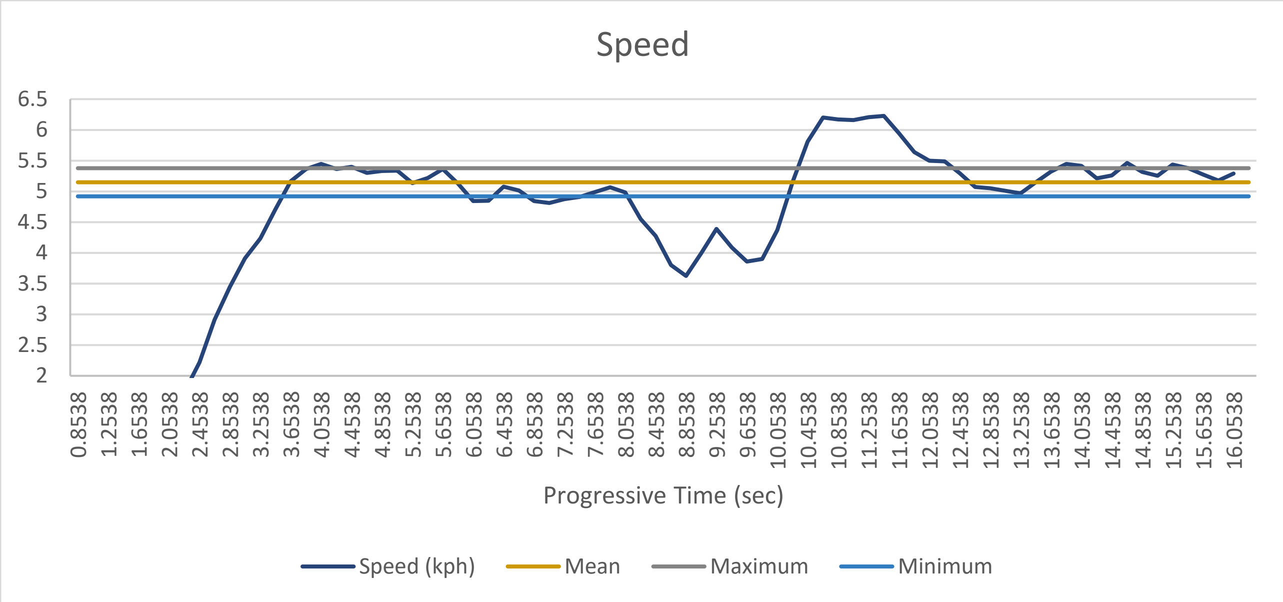
200mm – 5kph

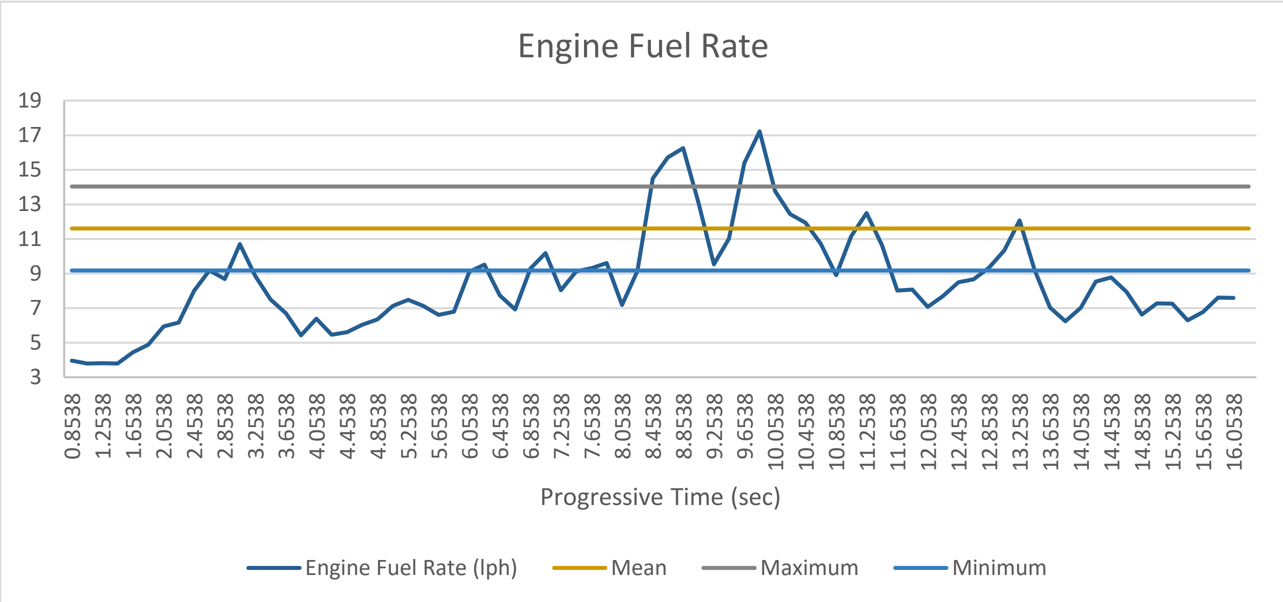


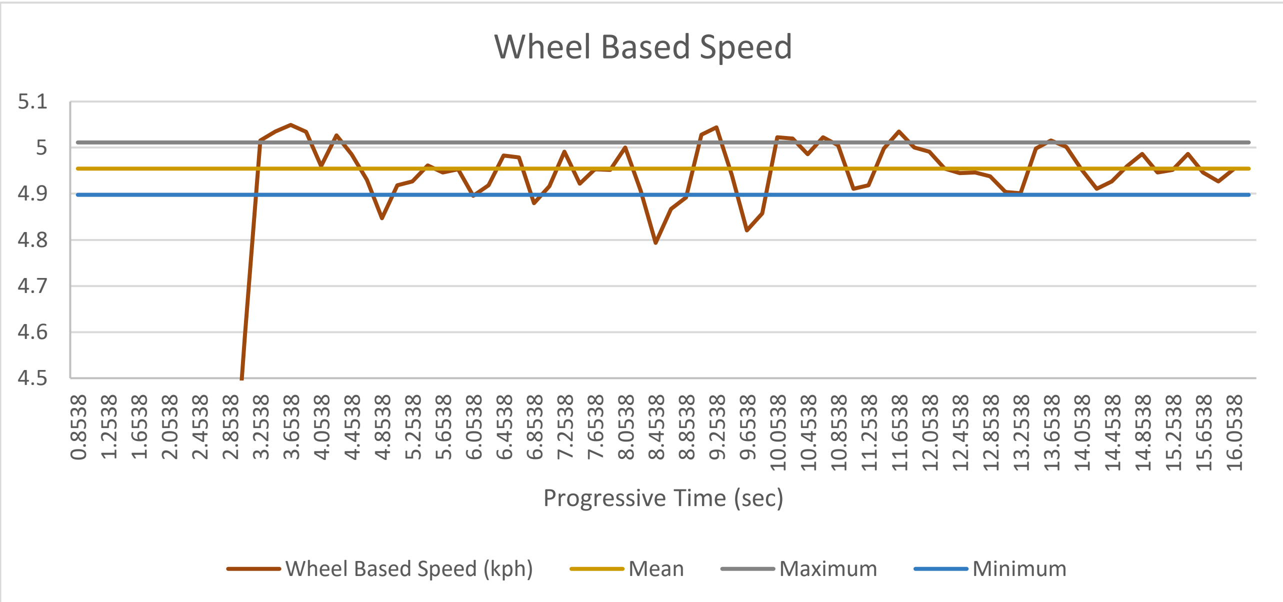
Tractor Parameters over Testing Period
120
100
80
60
40
20
0
2500
2000
1500
1000
500
0
Engine RPM
0.8538
1.4538
2.0538
2.6538
3.2538
3.8538
4.4538
5.0538
5.6538
6.2538
6.8538
7.4538
8.0538
8.6538
9.2538
9.8538
10.4538
11.0538
11.6538
12.2538
12.8538
13.4538
14.0538
14.6538
15.2538
15.8538
Progressive Time (sec)
engine fuel rate (lph)
speed
wheel based speed
engine coolant temp
Rear hitch %
Engine % load
Engine RPM

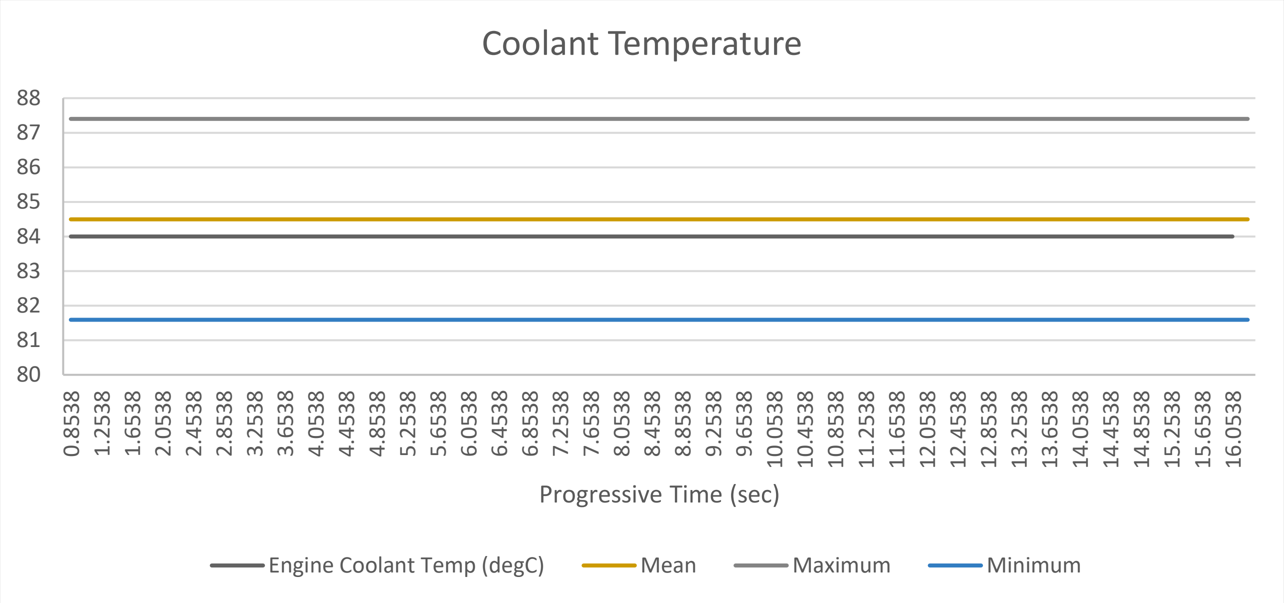


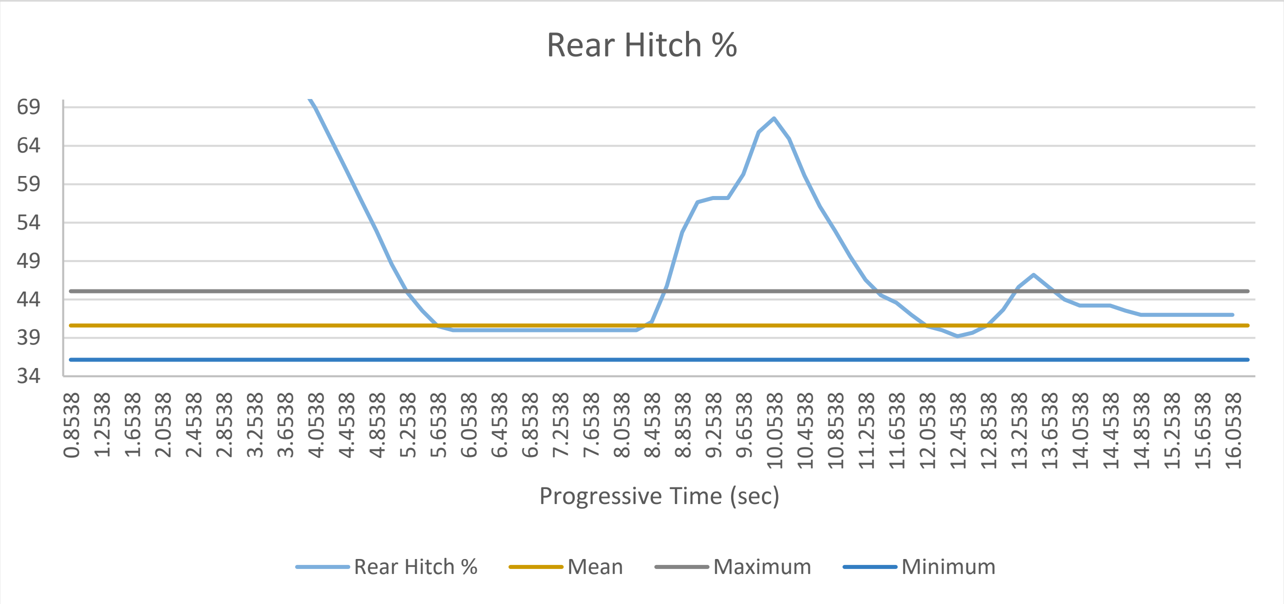
Engine Load
80
70
60
50
40
30
20
10
0.8538
1.2538
1.6538
2.0538
2.4538
2.8538
3.2538
3.6538
4.0538
4.4538
4.8538
5.2538
5.6538
6.0538
6.4538
6.8538
7.2538
7.6538
8.0538
8.4538
8.8538
9.2538
9.6538
10.0538
10.4538
10.8538
11.2538
11.6538
12.0538
12.4538
12.8538
13.2538
13.6538
14.0538
14.4538
14.8538
15.2538
15.6538
16.0538
Progressive Time (sec)
Engine % Load
Mean
Maximum
Minimum

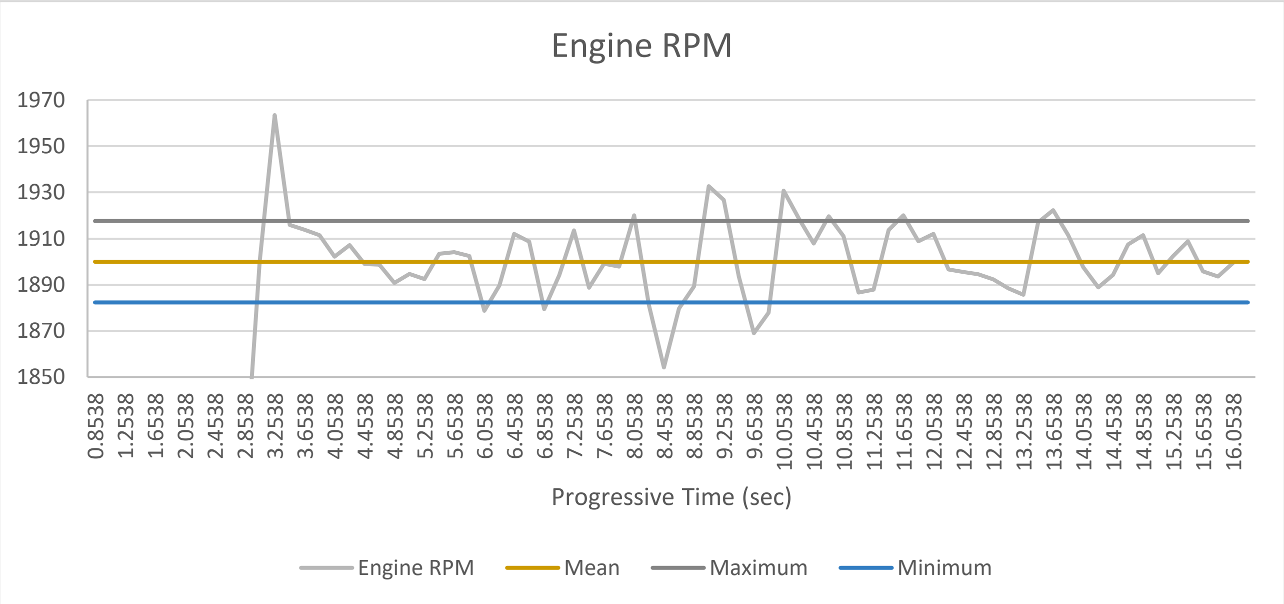

Speed
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Speed (kph)
Mean
Maximum
Minimum


Engine Fuel Rate
19
17
15
13
11
9
7
5
3
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Engine Fuel Rate (lph)
Mean
Maximum
Minimum


Wheel Based Speed
5.1
5
4.9
4.8
4.7
4.6
4.5
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Wheel Based Speed (kph)
Mean
Maximum
Minimum

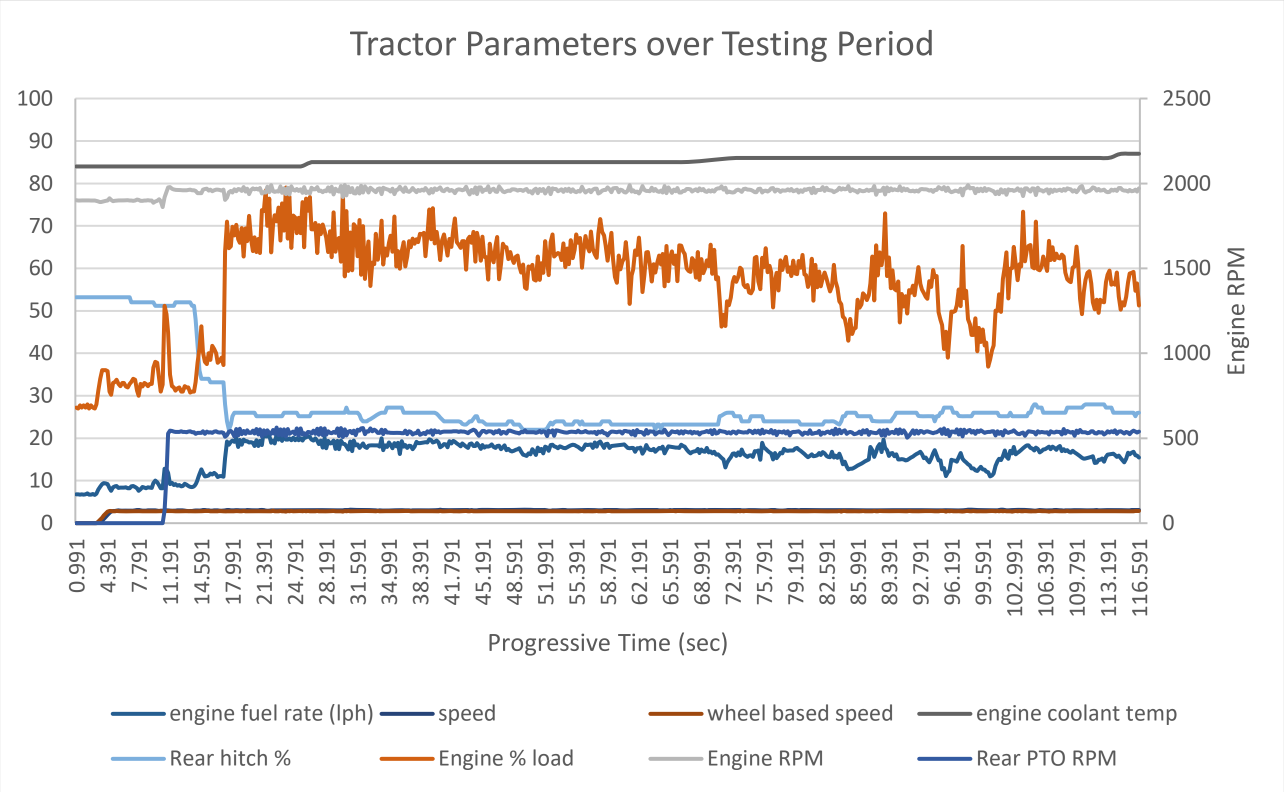

Coolant Temperature
88
87
86
85
84
83
82
81
80
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Engine Coolant Temp (degC)
Mean
Maximum
Minimum


Rear Hitch %
69
64
59
54
49
44
39
34
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Rear Hitch %
Mean
Maximum
Minimum

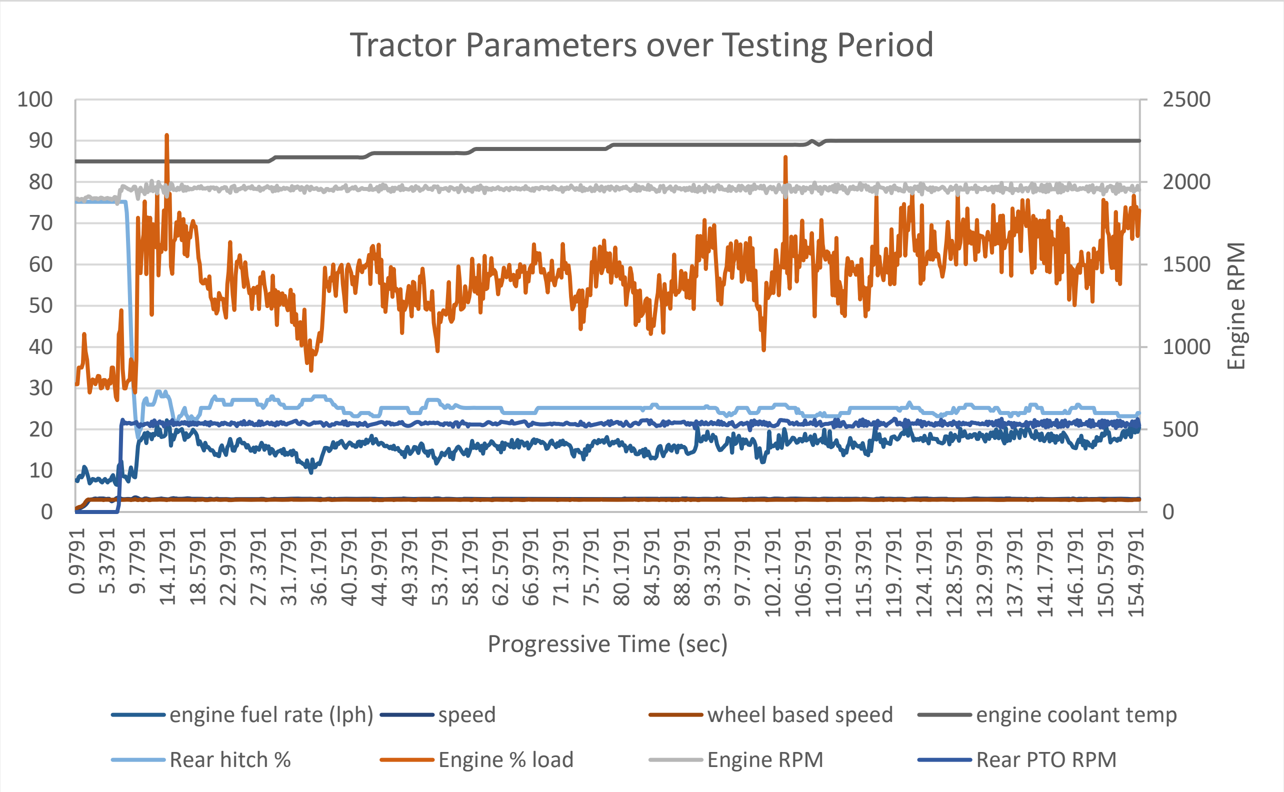

Engine RPM
1970
1950
1930
1910
1890
1870
1850
0.8538 1.2538 1.6538 2.0538 2.4538 2.8538 3.2538 3.6538 4.0538 4.4538 4.8538 5.2538 5.6538 6.0538 6.4538 6.8538 7.2538 7.6538 8.0538 8.4538 8.8538 9.2538 9.6538 10.0538 10.4538 10.8538 11.2538 11.6538 12.0538 12.4538 12.8538 13.2538 13.6538 14.0538 14.4538 14.8538 15.2538 15.6538 16.0538
Progressive Time (sec)
Engine RPM
Mean
Maximum
Minimum

Appendix M – PTO Powered Mulcher – Virgin ground data

150mm - 3kph

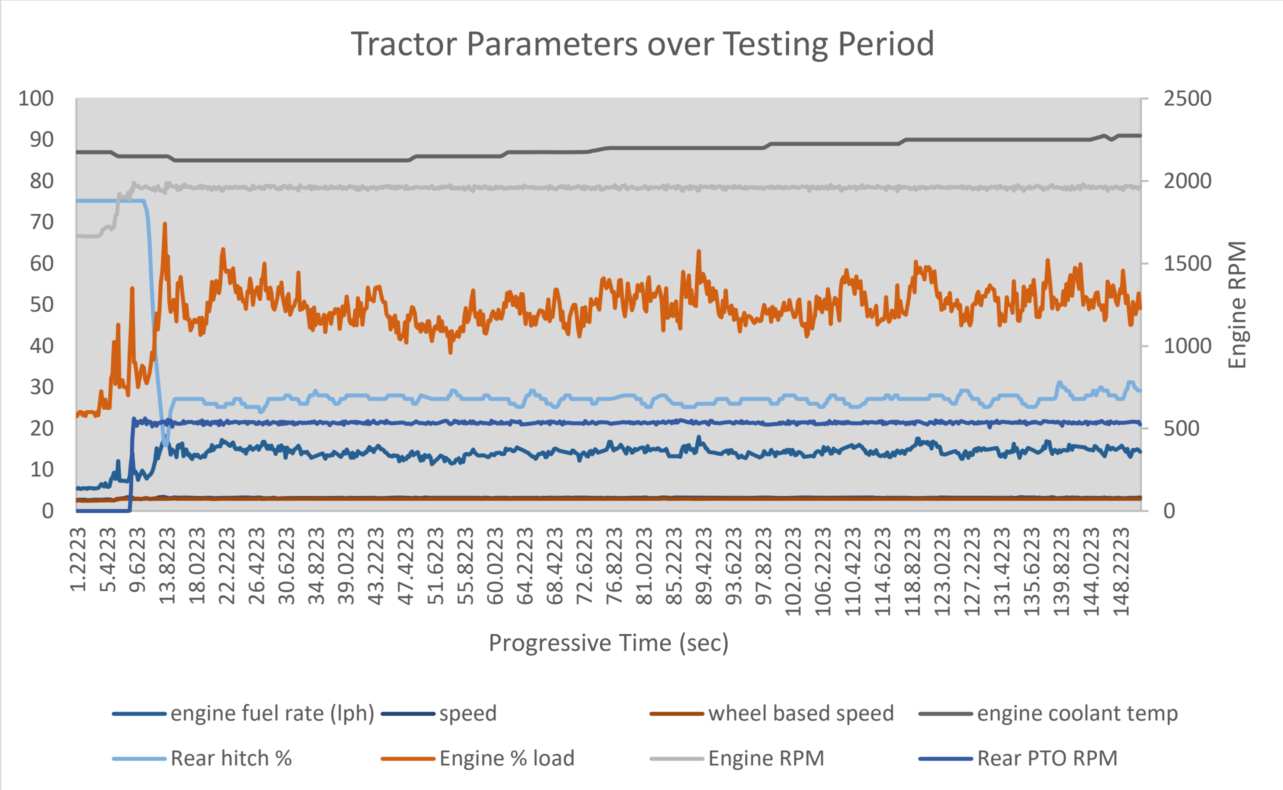


150mm - 3kph – 2

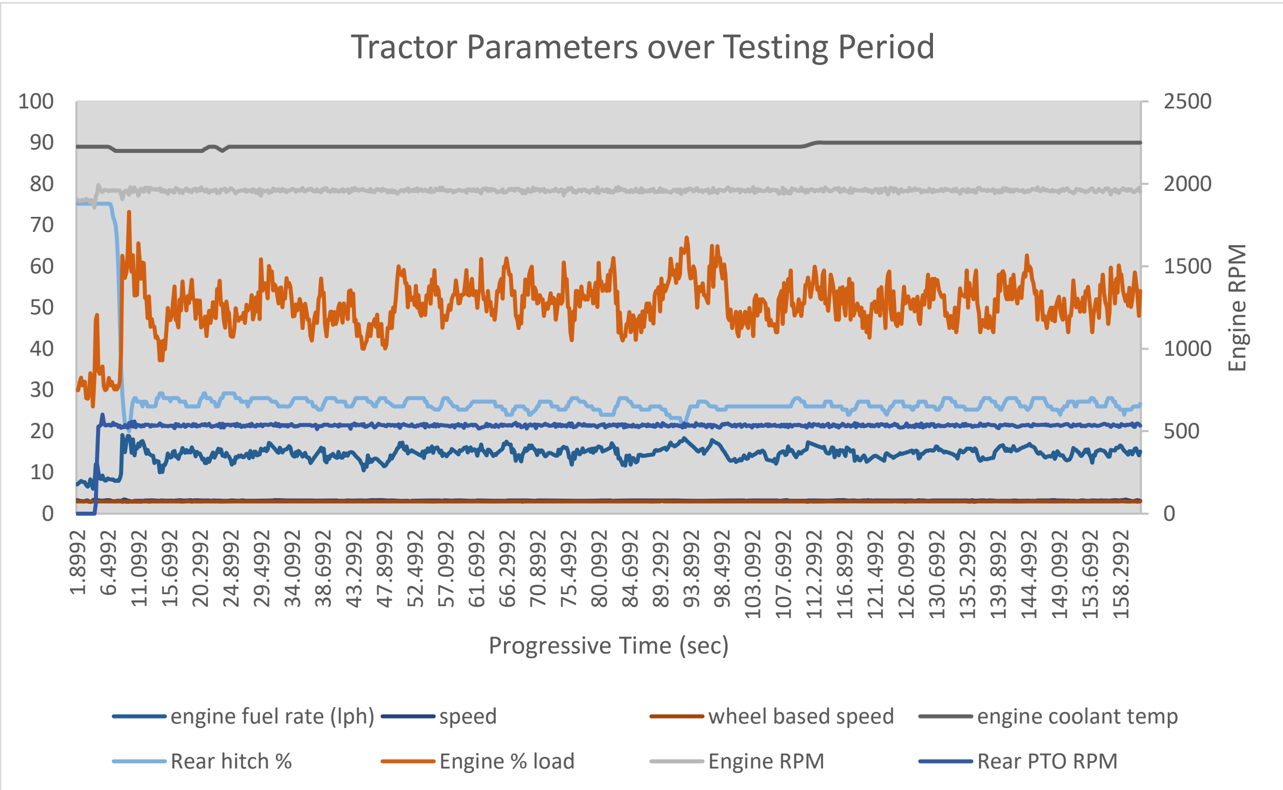


Appendix N – PTO Powered Mulcher – Pre-ripped ground data

150mm - 3kph



150mm - 3kph – 2



Appendix O - Timeline

		Semester 1																	Semester 2																		
		March				April				May				June				July				August				September				October				November		
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
	Supervisor meeting																																			
Initial Investigation	How to collect data from the CAN																																			
	Determine which data is useful																																			
	Find existing data already available to operator																																			
	Find data on CAN that will be useful																																			
	Literature Review																																			
Experiment Process	Develop experiment procedure														EXAMS		Mid-Sem																EXAMS			
	Secure site and machinery for testing																																			
	Perform the data collection																																			
Data Analysis	Determine the suitability of the data																																			
	Draw conculsions about data and how it relates																																			
Writeup	Prepare draft of final report																																			
	Finalise report for submission																																			

Appendix P - USQ Safety Risk Management Plan

UNIVERSITY OF SOUTHERN QUEENSLAND

USQ Safety Risk Management System

Safety Risk Management Plan

Risk Management Plan ID: RMP_2022_6782	Status: Approve
Approver: Craig Baillie	Supervisor: Sam Green

Assessment Title:	Tractor operation for data collection for research project
Assessment Date:	2022-03-16
Workplace (Division/Faculty/Section):	457000 - Centre for Agricultural Engineering
Review Date:	

Context

DESCRIPTION

What is the tast/event/purchase/project/procedure?	Collecting data using the tractors at USQ as well as some of the tillage equipment
Why is it being conducted?	To collect data for a student research project
Where is it being conducted?	Throughout the CAE
Course code (if applicable)	ENG4111
ChemicalName (if applicable)	

WHAT ARE THE NORMAL CONDITIONS?

Personnel involved	Sam Green
Equipment	John Deere tractors, tillage equipment
Environment	Various plots around the CAE
Other	
Briefly explain the procedure/process	Tillage operations will be undertaken using the tractor and then a modification will be made to the implement and the data collected again to allow differences to be identified.

Assessment Team - who is conducting the assessment?

Accessor(s)	Sam Green
Others consulted:	

Draft Approval

Drafters Name:	*Sam Green*	*Draft Date: 2022-03-16*
Drafters Comments:		

Assessment Approval:	There are risks not marked as ALARP
Maximum Residual Risk Level:	Low - Manager/Supervisor Approval Required

Approval

Approvers Name:	*Craig Baillie*
Approvers Position Title:	*HoS, School of Agriculture and Environmental Science*
ApproversComments:	*Common Sense is more appropriately termed as assessing the situation before interacting with machinery.*

Approval Decision:	*Approve*	*Approval/Reject Date:*	*2022-03-30*

Supporting Attachments

Risk Register and Analysis

RiskID: 1	Hazards: Working alone	
The Risk:	Becoming trapped in the machine	
Consequence:	Minor	
Existing Controls:	Use common sense and make sure objects cannot fall on the user. Ensure the person has the safezone app on a mobile phone that could be used to contact someone	
Probability:	Rare	
Risk Level:	Low	
ALARP:	NO	
Additional Controls:		
Additional Consequence:		
Additional Risk Level:		
Additional Probability:		
Additional ALARP:	NO	
Exclude From Action Plan:		
Resources:		
Proposed Implementation Date:		
Persons Responsible:		
Residual Risk Level:	Low	Not ALARP: !

RiskID: 2	Hazards: Working in temperatures above 35 degrees	
The Risk:	Heat exhaustion and stress	
Consequence:	Insignificant	
Existing Controls:	Regular breaks during summer, breathable clothing and cool drinks available	
Probability:	Rare	
Risk Level:	Low	
ALARP:	NO	
Additional Controls:		
Additional Consequence:		
Additional Risk Level:		
Additional Probability:		
Additional ALARP:	NO	
Exclude From Action Plan:		
Resources:		
Proposed Implementation Date:		
Persons Responsible:		
Residual Risk Level:	Low	Not ALARP: !

RiskID: 3	Hazards: Injury from plants and equipment in the field	
The Risk:	Person could become injured if they are contacted by a dangerous plant or other euipment in the field such as irrigation infrastructure	
Consequence:	Minor	
Existing Controls:	Ensure correct PPE is worn for outside working and long pants and shirts are worn to protect from dangerous plants	
Probability:	Rare	
Risk Level:	Low	
ALARP:	NO	
Additional Controls:		
Additional Consequence:		
Additional Risk Level:		
Additional Probability:		
Additional ALARP:	NO	
Exclude From Action Plan:		
Resources:		
Proposed Implementation Date:		
Persons Responsible:		
Residual Risk Level:	Low	Not ALARP: !

RiskID: 4	Hazards: Heavy machinery
The Risk:	Getting run over by the heavy machinery such as the tractors and the sprayer
Consequence:	Insignificant
Existing Controls:	When operating machinery ensure people are clear from the area before starting keep your eyes up when machinery is being used. don't park smaller vehicles behind other vehicles or where they cannot be seen.
Probability:	Rare
Risk Level:	Low
ALARP:	NO
Additional Controls:	
Additional Consequence:	
Additional Risk Level:	
Additional Probability:	
Additional ALARP:	NO
Exclude From Action Plan:	
Resources:	
Proposed Implementation Date:	
Persons Responsible:	
Residual Risk Level:	Low Not ALARP: !

Risk Matrix					
	Consequence				
Probability	Insignificant No Injury 0-$5K	Minor First Aid $5K-$50K	Moderate Med Treatment $50K-$100K	Major Serious Injury $100K-$250K	Catastrophic Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1,000	L	M	H	H	H
Unlikely 1 in 10,000	L	L	M	M	M
Rare 1 in 1,000,000	L	L	L	L	L

Recommended Action Guide	
Extreme:	E= Extreme Risk – Task ***MUST NOT*** proceed
High:	**H** = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	M= Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	L= Low Risk - Manage by routine procedures.